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Description and appraisal of methods of calculating the z3-effect correction

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DESCRIPTION AND APPRAISAL OF METHODS OF CALCULATING THE z^3-EFFECT CORRECTION

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The Barkas effect in the stopping power field deals with the z^3-correction for a projectile of specified atomic number, z. Several articles on this subject, such as J. C. Ashley's papers, J. D. Jackson and R. L. McCarthy's paper, and S. H. Morgan and C. C. Sung's paper were valuable. These authors' different methods of approaching the z^3-correction were compared; then their formulas were used to calculate the values of the z^3-correction term for different target materials -- chemical elements from 1 to 18 -- as the projectile velocity varied from 3×10^7 m/s to 1×10^8 m/s. The results calculated from these three formulas were compared with the experimental data: in the low-energy range (i. e., between 0.5 MeV and 4.5 MeV), Ashley's method best fits the experimental data; in the high-energy range (i. e., between 4.5 MeV and 20.0 MeV), Morgan and Sung's method best fits the experimental data.

This thesis provides a substantial number of charts for the z^3-correction term, which will assist researchers in this field. It also provides energy-velocity conversion charts and tables for proton and α-particle projectiles for β-values from 0.001 to 0.300.

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CHAPTER I

INTRODUCTION

In the early days of this century, when α-rays and ß-rays became available, many scientists were interested in studying a new phenomenon: while charged particles penetrate matter, their velocity decreases. Scientists tried to get some hints from this phenomenon to discover what is really inside the atoms.

The first atomic model was given by Sir J. J. Thomson in 1903. He visualized an atom as a sphere of positively charged massive material with a multitude of tiny electrons spread throughout its body, and electrons within the atom were supposed to be at rest at certain equilibrium positions. Laborious calculations were carried out in the attempt to correlate the vibration frequencies of different electronic configurations with the observed line spectra of various chemical elements, but this work was in vain.

After Professor E. Rutherford's work on the scattering of α-rays by matter in 1911, a new model was established. The model is that the atoms of matter are supposed to consist of a cluster of electrons kept together by the force of attraction from a nucleus; this nucleus, which possesses a positive charge equal to the sum of the negative charges on the electrons, is further supposed to constitute most of the mass of the atom, and to have dimensions which are exceedingly small compared with the dimensions of the atom.

In 1913 and 1915, based on the Rutherford model, N. Bohr published his first two articles about the decrease of velocity of moving electrified particles in passing through matter [1,2]. He gave the first definition of stopping power -- energy loss in collisions -- and derived the formula to calculate the stopping power. He used an impact parameter to characterize the transfer of energy from the incident particle to the electrons of the target material.

Since the Bohr method was a classical method, his theory had limited accuracy and applied over only a limited range of projectile energies. From 1930 to 1933, H. Bethe and F. Bloch developed another approach with their quantum mechanical method [3]. They used a first-order quantum mechanical approach characterized by momentum transfer to calculate the stopping power. In their formulas, the stopping power, S (to be defined later), is a function of the stopping number, L (to be defined later): [$S = f(L)$]. The stopping number can be expanded into three basic terms [$L = L_0 + zL_1 + L_2$]. The first term of the stopping number is a function of the square of the projectile atomic number, the second term the cube of the projectile atomic number, and the third term the fourth power and higher even powers of the projectile atomic number. Nowadays, whereas the third term was indisputably established by F. Bloch in 1932, the first and second terms are still the subject of debate among physicists. The second term is called the Barkas-effect correction, which is the correction of the term related to the cube of the projectile atomic number.

In 1956, the Barkas effect was observed by experiment [4]. The experiment showed that slow negative hyperons lose energy at a slower rate than do positive particles at the same velocity.

In 1963, a representative review article was published by U. Fano [3]. Since then, many articles have been written and many experiments have been done [5,6,7,8]. For the correction of the term related to the cube of the projectile-atomic-number term, theoretical work has been done by J. C. Ashley, R. H. Ritchie and W. Brandt [9,10,11,12]; by S. H. Morgan and C. C. Sung [13]; and by J. D. Jackson and R. L. McCarthy [14]. These groups used different approaches to calculate the second term of the stopping number, which includes the Z^3-correction.

This paper compares those authors' different methods of approaching the z^3-correction by using their formulas to calculate the values of the z^3-correction term for different target materials. By adding the term to both the first term value, which is provided by Dr. L. E. Porter's new method of calculation, and to the third term's indisputable value, we can calculate the stopping power, and then compare it with experimental data.

These calculations were done for two kinds of projectiles (protons and alpha particles) on each of 18 target materials (chemical elements with atomic numbers 1 to 18).

The analysis of these data was done with the aid of computer programs written by the author. These FORTRAN programs, shown in Appendix I, are based on the parabolic interpolation method and the least squares method and use the technology of graphics.

CHAPTER II

THEORY

The stopping power, S, in units of $MeV \cdot cm^2/g$, of a material is defined by

$$S = - \frac{1}{\rho} \frac{dE}{dX} \qquad (1)$$

Here ρ is the density of the target material in g/cm^3, and dE/dx is the average rate of energy loss of the projectiles per unit path length in MeV/cm.

By the theory of Bethe-Bloch [3], the formula of stopping power can be derived as

$$S = \frac{4\pi e^4 N_0 z^2 ZL}{mc^2 \beta^2 A} \qquad (2)$$

where the quantity

$$\frac{4\pi e^4 N_0}{mc^2} \approx 0.30708$$

when S is given in $MeV \cdot cm^2/g$. The symbols in the stopping power formula represent the following quantities:

e = electronic charge

N_0 = Avogadro's number

m = rest mass of electron

c = the speed of light in vacuum

β = v/c = velocity of projectile / velocity of light

z = charge of incident particle in units of e

Z = atomic number of target material

A = atomic weight of target material

L = stopping number per target electron.

The stopping number per target electron consists of three terms that contain all of the undetermined parameters.

$$L = L_0(\beta) + zL_1(\beta) + L_2(\beta) \qquad (3)$$

The first term in Eq.(3), L_0, that derived from basic Bethe-Bloch theory [10,12], is given by

$$L_0 = f(\beta) - \ln(I) - \sum_i C_i/Z - \delta/2, \qquad (4)$$

where

$$f(\beta) = \ln[2mc^2\beta^2/(1-\beta^2)] - \beta^2. \qquad (5)$$

These symbols represent the following quantities:

mc^2 = rest-mass energy of the electron

I = mean excitation energy

δ = high velocity density effect correction

C_i = shell correction for the i^{th} shell

where i = K refers to the K-shell electrons, i = L refers to the L-shell electrons, etc. The shell corrections are obtained with the sum [15]

$$\sum_i C_i = B_K C_K(\beta^2) + V_L C_L(H_L\beta^2) + V_M C_L(H_M\beta^2) + V_N C_L(H_N\beta^2), \qquad (6)$$

Where C_K and C_L are the K- and L-shell corrections calculated by Walske [16,17], and corrections for M and N shells are taken to be of the same form as the L-shell correction with adjustable scaling parameters appearing in transparent notation.

Since the experimental data of the incident particle rarely goes up to 20 MeV, the energy range between 0.5 MeV and 20.0 MeV of the incident particle has been considered here.

In this paper, L_1 was calculated by Dr. L. E. Porter with advanced methods from his recent work [18].

The third term in Eq.(3), L_2, was given by Bloch [19] as

$$L_2(y) = \psi(1) - \mathrm{Re}[\psi(1+iy)], \qquad (7)$$

where $y = z\alpha/\beta$, with α the fine-structure constant, and ψ is the logarithmic derivative of the gamma function [20]. This term can be represented by the series [20],

$$L_2(y) = -y^2 \sum_{j=1}^{\infty} j^{-1}(j^2 + y^2)^{-1}, \qquad (8)$$

and therefore is always negative. For $y^2 < 1$, L_2 can be approximated to within 0.4% by the function [21],

$$\bar{L}_2(y) = -y^2[1.20206-y^2(1.042-0.8549y^2+0.343y^4)]. \quad (9)$$

The second term in Eq.(3), L_1, was added as a correction to the stopping number in order to account for the different rates at which positive and negative pions lose energy when traversing matter [6]. The forms of L_1 vary with different approaches. Following are three kinds of approaches.

A. L_1 derived by J. C. Ashley, et al.

The form of L_1 derived by J. C. Ashley, et al. [9,10,11,12] is

$$L_1 = \frac{F(b/x^{1/2})}{Z^{1/2}x^{3/2}} , \qquad (10)$$

where $F(b/x^{1/2})$ is a function derived and tabulated in refs. [9] and [10]. The symbols in this L_1 formula represent the following quantities:

b = parameter related to the minimum impact parameter cutoff

x = $(137\beta)^2 Z^{-1}$

Z = atomic number of target material

B. L_1 derived by J. D. Jackson and R. L. McCarthy

The form of L_1 derived by J. D. Jackson and R. L. McCarthy [13] is

$$L_1 = \frac{3\pi}{8(137\beta)^3} \frac{S(1)}{S(0)} [\ln(2mv^2/R) - \frac{L(1)}{S(1)} - 1.04]. \quad (11)$$

The symbols in this L_1 formula represent the following quantities:

S(a) = moment of the total oscillator-strength distribution

L(a) = moment containing the additional weight factor

(a is 0 or 1, see ref. [22])

m = rest mass of electron

v = the velocity of projectile

R = the Rydberg energy (13.6 eV).

C. L_1 derived by S. H. Morgan and C. C. Sung

The form of L_1 derived by S. H. Morgan and C. C. Sung [13] is

$$L_1 = \frac{\pi}{4(137\beta)^2}\,\frac{S(1)}{S(0)}\left[\left(\frac{\bar{E}}{R}\,\frac{S(0)}{S(1)} - 1\right)\ln(2mv^2/R) - \frac{\bar{E}}{R}\,\frac{L(0)}{S(1)} + \frac{L(1)}{S(1)}\right]. \quad (12)$$

The symbols in this L_1 formula represent the following quantities:

$\bar{E}$ = the average excitation energy of the intermediate states

(Others are the same as in Eq. (11).)

If we consider only one excitation level, namely, the 1S -> 2P excitation, then

$\bar{E}$ > (E_{2p} - E_{1s})

That means $\bar{E}$ must correspond to at least the E_{3p} energy level.

The estimated value of $\bar{E}$ was given by

$$\bar{E} \approx E_{3p} - E_{1s} \qquad (13)$$

Eq. (13) was obtained from the first optically allowed state only, or Eq. (13) would have been much more complicated. In this paper, the values of the average excitation energies of the intermediate states are borrowed from S. H. Morgan and C. C. Sung's paper [13]. They are

$$\frac{\bar{E}}{R} = 100 \qquad \text{and} \qquad \frac{\bar{E}}{R} = 125 .$$

There are certain similarities between the formulas derived by J. D. Jackson and R. L. McCarthy and by S. H. Morgan and C. C. Sung. Both have the same v^{-2} velocity dependence and both are proportional to S(1). S(1) is approximately equal to the absolute value of the total binding energy and S(0) = Z from the oscillator strength sum rule [22]. From both of their formulas, the logarithmic term will be the dominant term for high energies. This term is proportional to the difference between the average excitation energy of the intermediate states and the absolute value of the binding energy per atomic electron.

CHARTER III

CALCULATION

Since the stopping power depends on the stopping number, the stopping number needs to be calculated first.

The way to get the stopping number is to calculate L_0, L_1 and L_2, and then to follow the formula,
$L = L_0 + zL_1 + L_2$, to get the value of L.

The L_0 data are listed in Appendix II. They are provided by Dr. L. E. Porter with his method of calculation devised in 1989. To get a smooth relationship between L_0 and β, the parabolic interpolation method has been used. A sample computer program is listed in Appendix I, FAL.FOR .

There are three ways to get the L_1 value. To calculate L_1 with Ashley's method, one needs to find the value of F(w) for various targets and projectile speeds. F(w) is a tabular function in ref. [9]. To get a smooth relationship between F(w) and w, the parabolic interpolation method has been used. The computer program is listed in Appendix I, FW.FOR .

To calculate L_1 with J. D. Jackson's method, one needs to know the S(a), the moment of the total oscillator-strength distribution, and L(a), the moment containing the additional weight factor. These quantities vary from target to target. Here the data come from ref. [22].

To calculate L_1 with C. C. Sung's method, one needs to know the value of $\bar{E}$. Here C. C. Sung's selection has been borrowed, which is $\bar{E}/R = 100$ and $\bar{E}/R = 125$. Moreover S(0), S(1),L(0),L(1) also come from ref. [22]. Thus in this paper, there are two L_1 values calculated from C. C. Sung's method.

For all the L_1's, the computer program is listed in Appendix I, SUBL1.FOR .

The L_2 calculation is based on the following equation,

$$L_2(y) = -y^2 \sum_{j=1}^{\infty} j^{-1} (j^2 + y^2)^{-1},$$

where $y = z\,\alpha/\beta$ with α the fine structure constant. The computer program, listed in Appendix I, FL2.FOR, has an accuracy of 0.1%.

After the stopping number had been calculated, the formula

$$S = 0.30708 \frac{z^2 ZL}{\beta^2 A}$$

was used to calculate the stopping power.

Since the stopping power's theoretical value is different from theory to theory, experimental data comparisons are needed. Here, the least squares method is used to ascertain which theory provides the **smallest** relative error. The formula is

$$\sigma = [\frac{1}{N} \sum_{i=1}^{N} (\frac{S - S_{exp}}{S})^2]^{1/2} ,$$

where N is the number of experimental data points.

A sample computer program is listed in Appendix I, ALANDP.FOR .

CHAPTER IV

RESULTS

After the experimental data was entered into the computer and the programs were run, the first result to be obtained was:

<u>For β values smaller than 0.1, only Ashley's theory matched the experimental data very well, and both the theories of J. D. Jackson and R. L. McCarthy and of S. H. Morgan and C. C. Sung did not fit the experimental data at all</u>.

Sample programs are listed in Appendix I. Data come from refs. [24 to 47].

For protons bombarding H_2 at 0.5 MeV, for example, the value of L_1/L_0 from J. C. Ashley's method is 0.0114; the value from J. D. Jackson and R. L. McCarthy's method is a negative value, -0.0103, and the value from S. H. Morgan and C. C. Sung's method is 0.6315 for $\bar{\epsilon}/R$ = 100 and 0.7885 for $\bar{\epsilon}/R$ = 125.

Since L_1 is the correction term for the Barkas effect, which is a positive effect for the z^3-correction when the projectile is positively charged, Jackson and McCarthy's method, which gives a negative value, seems invalid in this low-energy range. Since L_1 is a correction term added to L_0, it should be small compared to the L_0 term. However, Morgan and Sung's method yields an L_1/L_0 ratio that exceeds 60%. So Morgan and Sung's method also is not valid in the low energy range.

Secondly, the stopping power calculated by Ashley's method was picked to compare with the value published in the handbook of stopping cross-sections for energetic ions in all elements for the low energy range [23]. <u>All the data match very well</u>.

The stopping power data list follows (in units of $MeV \cdot cm^2/g$). E stands for Energy in the units of MeV, B stands for the handbook, M stands for my calculation result, and the * stands for the lack of data.

TABLE I

COMPARISON OF STOPPING POWER OF H AND He

FOR PROTON AND α PARTICLE PROJECTILES

Projectile proton, Target H

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.18,	0.65,	0.49,	0.38,	0.33,	0.28,	0.24,	0.22,	0.20,	0.18
M	1.16,	0.68,	0.49,	0.39,	0.33,	0.28,	0.25,	0.22,	0.20,	0.18

Projectile α particle, Target H

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	4.45,	2.61,	2.00,	1.56,	1.30,	1.24,	0.98,	0.88,	0.80,	0.73
M	4.59,	2.70,	1.96,	1.55,	1.30,	1.11,	0.98,	0.87,	0.80,	0.73

Projectile proton, Target He

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.47,	0.28,	0.21,	0.16,	0.14,	0.12,	0.11,	0.10,	0.09,	0.08
M	0.47,	0.29,	0.21,	0.17,	0.14,	0.12,	0.11,	0.10,	0.09,	0.08

Projectile α particle, Target He

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.83,	1.13,	0.85,	0.67,	0.55,	0.48,	0.44,	0.38,	0.34,	0.32
M	1.83,	1.14,	0.86,	0.67,	0.55,	0.48,	0.44,	0.38,	0.34,	0.32

TABLE II

COMPARISON OF STOPPING POWER OF Li AND Be FOR PROTON AND α PARTICLE PROJECTILES

Projectile proton, Target Li

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	*	*	*	*	*	*	*	*	*	*
M	0.58,	0.33,	0.24,	0.19,	0.15,	0.20,	0.10,	0.07,	0.05,	0.04

Projectile α particle, Target Li

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	*	*	*	*	*	*	*	*	*	*
M	2.31,	1.33,	0.95,	0.74,	0.59,	0.47,	0.37,	0.29,	0.21,	0.13

Projectile proton, Target Be

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.33,	0.22,	0.17,	0.13,	0.11,	0.10,	0.09,	0.08,	0.07,	0.07
M	0.38,	0.23,	0.18,	0.15,	0.13,	0.11,	0.10,	0.09,	0.08,	0.07

Projectile α particle, Target Be

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.38,	0.90,	0.70,	0.55,	0.47,	0.40,	0.34,	0.32,	0.29,	0.28
M	1.36,	0.82,	0.65,	0.53,	0.45,	0.39,	0.35,	0.31,	0.28,	0.26

TABLE III

COMPARISON OF STOPPING POWER OF B AND C FOR PROTON AND α PARTICLE PROJECTILES

Projectile proton, Target B

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.24,	0.22,	0.17,	0.13,	0.11,	0.10,	0.09,	0.08,	0.06,	0.07
M	0.33,	0.21,	0.16,	0.13,	0.11,	0.10,	0.09,	0.08,	0.07,	0.07

Projectile α particle, Target B

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.40,	0.86,	0.65,	0.53,	0.46,	0.39,	0.35,	0.32,	0.28,	0.26
M	1.34,	0.86,	0.65,	0.53,	0.45,	0.39,	0.35,	0.31,	0.29,	0.26

Projectile proton, Target C

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.35,	0.22,	0.18,	0.14,	0.12	0.11,	0.10,	0.08,	0.08,	0.07
M	0.36,	0.23,	0.17,	0.14,	0.12,	0.10,	0.09,	0.08,	0.08,	0.07

Projectile α particle, Target C

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.48,	0.92,	0.70,	0.58,	0.48,	0.42,	0.38,	0.33,	0.31,	0.28
M	1.48,	0.92,	0.69,	0.56,	0.48,	0.42,	0.37,	0.34,	0.31,	0.28

TABLE IV

COMPARISON OF STOPPING POWER OF N AND O FOR PROTON AND α PARTICLE PROJECTILES

Projectile proton, Target N

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.35,	0.22,	0.18,	0.14,	0.12,	0.10,	0.10,	0.08,	0.08,	0.07
M	0.36,	0.23,	0.17,	0.14,	0.12,	0.10,	0.09,	0.08,	0.08,	0.07

Projectile α particle, Target N

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.40,	0.90,	0.69,	0.56,	0.48,	0.42,	0.34,	0.32,	0.30,	0.28
M	1.47,	0.92,	0.69,	0.56,	0.47,	0.41,	0.37,	0.33,	0.30,	0.28

Projectile proton, Target O

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.34,	0.21,	0.16,	0.13,	0.12,	0.10,	0.09,	0.08,	0.07,	0.07
M	0.34,	0.22,	0.16,	0.13,	0.11,	0.10,	0.09,	0.08,	0.07,	0.07

Projectile α particle, Target O

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.28,	0.84,	0.65,	0.53,	0.46,	0.40,	0.35,	0.32,	0.29,	0.27
M	1.39,	0.88,	0.66,	0.54,	0.46,	0.40,	0.36,	0.32,	0.29,	0.27

TABLE V

COMPARISON OF STOPPING POWER OF F AND Ne

FOR PROTON AND α PARTICLE PROJECTILES

Projectile proton, Target F

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.28,	0.19,	0.15	*	*	*	*	*	*	*
M	*	*	*	*	*	*	*	*	*	*

Projectile α particle, Target F

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.11,	0.78,	0.59	*	*	*	*	*	*	*
M	*	*	*	*	*	*	*	*	*	*

Projectile proton, Target Ne

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.28,	0.19,	0.15,	0.12,	0.10,	0.09,	0.08,	0.07,	0.07,	0.06
M	0.28,	0.19,	0.15,	0.12,	0.10,	0.09,	0.08,	0.07,	0.06,	0.06

Projectile α particle, Target Ne

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.07,	0.86,	0.59,	0.49,	0.42,	0.36,	0.32,	0.29,	0.27,	0.23
M	1.17,	0.78,	0.59,	0.49,	0.42,	0.36,	0.33,	0.29,	0.27,	0.25

TABLE VI

COMPARISON OF STOPPING POWER OF Na AND Mg FOR PROTON AND α PARTICLE PROJECTILES

Projectile proton, Target Na

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	*	*	*	*	*	*	*	*	*	*
M	*	*	*	*	*	*	*	*	*	*

Projectile α particle, Target Na

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	*	*	*	*	*	*	*	*	*	*
M	*	*	*	*	*	*	*	*	*	*

Projectile proton, Target Mg

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.28,	0.19,	0.14,	0.12,	0.10,	0.09,	0.08,	0.07,	0.07,	0.06
M	*	*	*	*	*	*	*	*	*	*

Projectile α particle, Target Mg

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.10,	0.77,	0.58,	0.47,	0.40,	0.35,	0.32,	0.28,	0.26,	0.24
M	*	*	*	*	*	*	*	*	*	*

TABLE VII

COMPARISON OF STOPPING POWER OF Al AND Si FOR PROTON AND α PARTICLE PROJECTILES

Projectile proton, Target Al

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.26,	0.17,	0.13,	0.11,	0.09,	0.08,	0.07,	0.07,	0.06,	0.06
M	0.25,	0.17,	0.13,	0.11,	0.09,	0.08,	0.07,	0.07,	0.06,	0.06

Projectile α particle, Target Al

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.98,	0.72,	0.53,	0.42,	0.38,	0.34,	0.30,	0.27,	0.25,	0.22
M	0.97,	0.71,	0.53,	0.42,	0.38,	0.34,	0.30,	0.28,	0.26,	0.21

Projectile proton, Target Si

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.26,	0.18,	0.14,	0.11,	0.10,	0.09,	0.08,	0.07,	0.06,	0.06
M	0.26,	0.17,	0.14,	0.11,	0.10,	0.08,	0.08,	0.07,	0.06,	0.06

Projectile α particle, Target Si

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.02,	0.71,	0.56,	0.46,	0.40,	0.35,	0.31,	0.28,	0.26,	0.24
M	0.99,	0.70,	0.56,	0.47,	0.41,	0.35,	0.31,	0.29,	0.26,	0.23

TABLE VIII

COMPARISON OF STOPPING POWER OF P AND S

FOR PROTON AND α PARTICLE PROJECTILES

Projectile proton, Target P

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	*	*	*	*	*	*	*	*	*	*
M	*	*	*	*	*	*	*	*	*	*

Projectile α particle, Target P

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	*	*	*	*	*	*	*	*	*	*
M	*	*	*	*	*	*	*	*	*	*

Projectile proton, Target S

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	0.26,	0.17,	0.13,	0.11,	0.10,	0.08,	0.08,	0.07,	0.06,	0.06
M	0.25,	0.17,	0.13,	0.11,	0.09,	0.08,	0.07,	0.07,	0.06,	0.06

Projectile α particle, Target S

E	0.5,	1.0,	1.5,	2.0,	2.5,	3.0,	3.5,	4.0,	4.5,	5.0
B	1.30,	0.68,	0.52,	0.43,	0.38,	0.34,	0.30,	0.27,	0.25,	0.23
M	1.04,	0.69,	0.53,	0.44,	0.38,	0.33,	0.30,	0.27,	0.25,	0.23

TABLE IX

COMPARISON OF STOPPING POWER OF Cl AND Ar FOR PROTON AND α PARTICLE PROJECTILES

Projectile proton, Target Cl

E	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
B	0.25	0.16	0.10	*	*	*	*	*	*	*
M	*	*	*	*	*	*	*	*	*	*

Projectile α particle, Target Cl

E	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
B	0.98	0.65	0.51	*	*	*	*	*	*	*
M	*	*	*	*	*	*	*	*	*	*

Projectile proton, Target Ar

E	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
B	0.22	0.15	0.12	0.10	0.09	0.08	0.07	0.06	0.06	0.05
M	0.23	0.15	0.12	0.10	0.08	0.07	0.07	0.06	0.06	0.05

Projectile α particle, Target Ar

E	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
B	0.90	0.60	0.49	0.40	0.34	0.30	0.27	0.24	0.23	0.21
M	0.92	0.62	0.48	0.39	0.34	0.30	0.27	0.24	0.22	0.21

Based on the data above, when the projectiles are protons, the data matches better than when the projectiles are α particles in the low-energy range. This is because when the β of the projectiles is less than 0.033, the shell correction becomes negative and hence should be considered unreliable [18]. So for α projectiles, the first two values of each element data list above do not match with the book values as well as do other values.

On the other hand, in the high energy range (about 3 MeV to 20 MeV for protons as projectiles), a comparison of the theoretical values of stopping power and experimental data has been carried out for aluminum. Computer programs are listed in Appendix I. The result shows:

I. When the projectile energy is between 2.3 MeV and 4.5 MeV ($0.07 < \beta < 0.10$), Ashley's method has a lower relative error compared to the other methods. Morgan and Sung's method has the biggest error in this energy range (see chart I).

CHART I

RELATIVE ERROR AMONG THEORIES IN THE RANGE OF

$0.07 < \beta < 0.10$ FOR ALUMINUM

Theories	Relative errors
Ashley, *et al.*	1.2%
Jackson and McCarthy	2.3%
Morgan and Sung, $\bar{\varepsilon}/R = 100$	3.5%
Morgan and Sung, $\bar{\varepsilon}/R = 125$	5.0%

II. When the projectile energy is between 4.5 MeV and 5.5 MeV ($0.10 < \beta < 0.11$), the results of Morgan and Sung's method improve. While Ashley's method remains accurate, Morgan and Sung's method for $\bar{\varepsilon}/R = 100$ provides the best fits to the experimental data (see chart II).

CHART II

RELATIVE ERROR AMONG THEORIES IN THE RANGE OF

$0.10 < \beta < 0.11$ FOR ALUMINUM

Theories	Relative errors
Ashley, *et al.*	1.2%
Jackson and McCarthy	1.5%
Morgan and Sung, $\bar{\varepsilon}/R = 100$	0.8%
Morgan and Sung, $\bar{\varepsilon}/R = 125$	1.5%

<u>III. When the projectile energy is between 5.5 MeV and 20 MeV (0.11 < β < 0.20), Morgan and Sung's method becomes far more accurate.</u> Both the $\bar{E}/R$ = 100 and $\bar{E}/R$ =125 results better fit the experimental data than Ashley's method. Compared to the other methods, Jackson and McCarthy's method in this energy range has the biggest relative error (see chart III).

CHART III

RELATIVE ERROR AMONG THEORIES IN THE RANGE OF

0.11 < β < 0.20 FOR ALUMINUM

Theories	Relative errors
Ashley, <u>et</u> <u>al</u>.	1.0%
Jackson and McCarthy	1.1%
Morgan and Sung, $\bar{E}/R$ = 100	0.5%
Morgan and Sung, $\bar{E}/R$ = 125	0.5%

Finally, the relationship among L_i's for all the methods has been plotted out for all the 18 chemical elements (see Figures 1 - 18). Using the L_i figures in conjunction with the relative error charts, one may easily decide what theory will best apply to the different energy ranges and will yield the most accurate results.

Figure of L_1 vs. Beta for four different calculations (H)

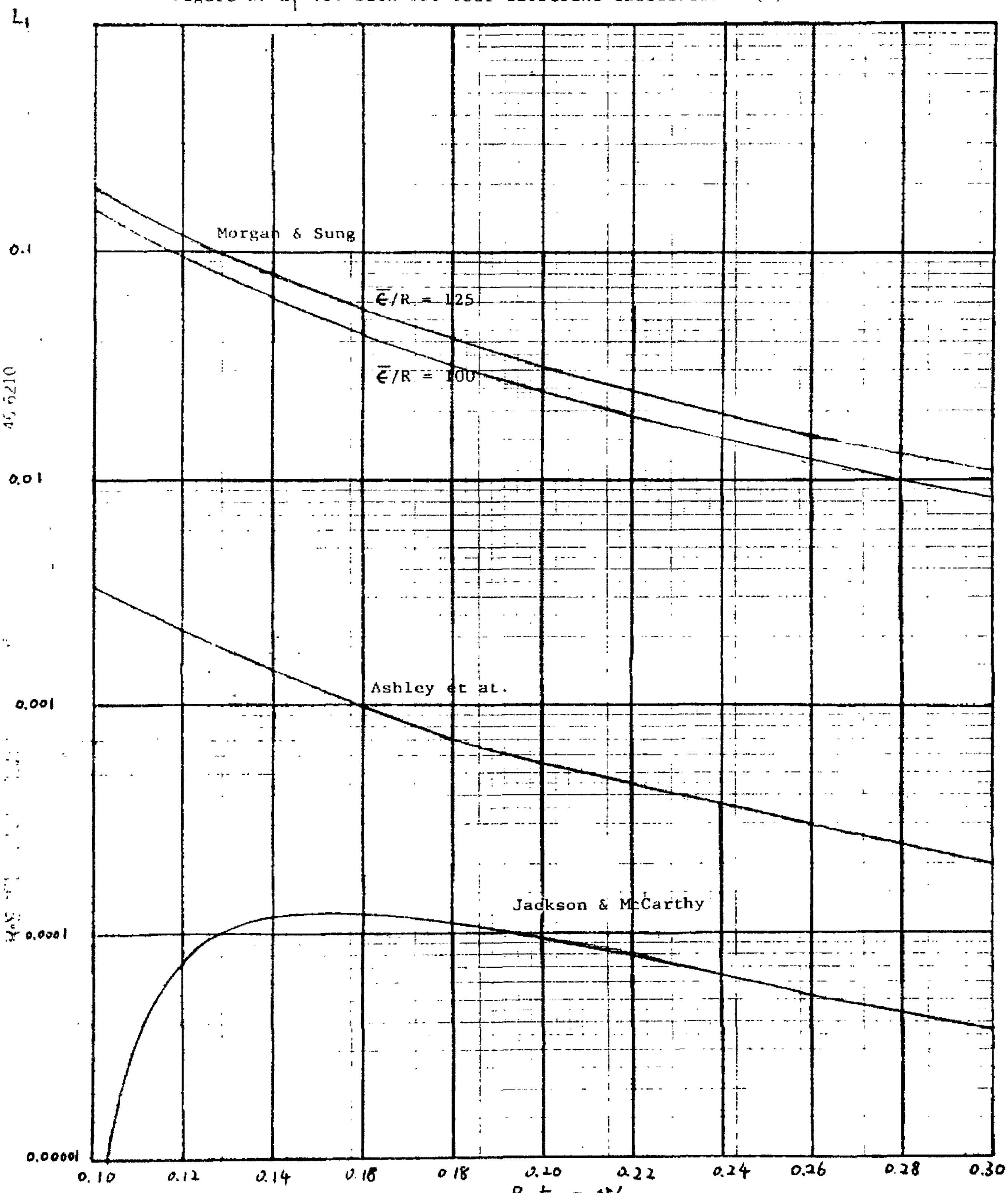


Figure of L_1 vs. Beta for four different calculations (He)

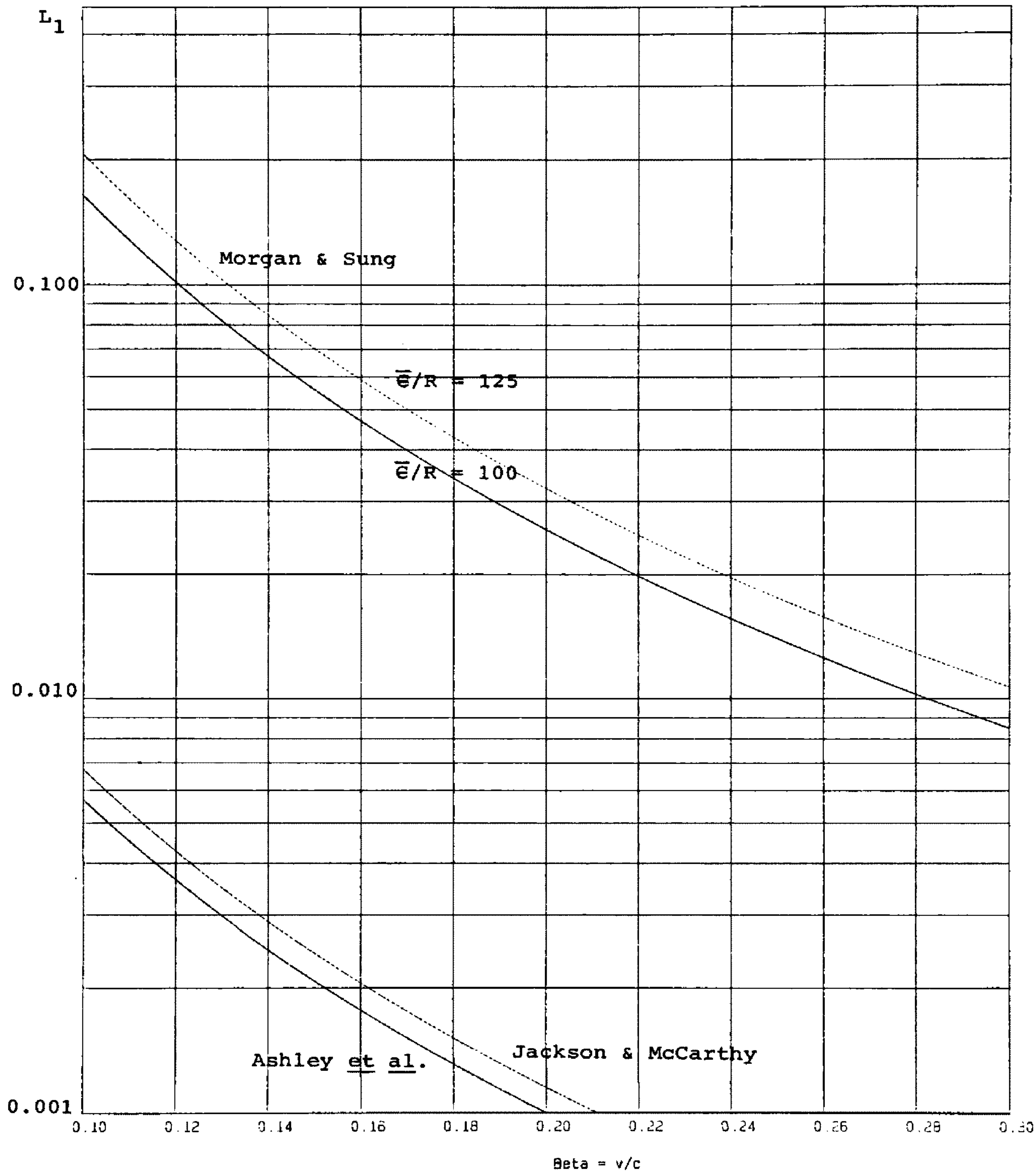


Figure of L_1 vs. Beta for four different calculations (Li)

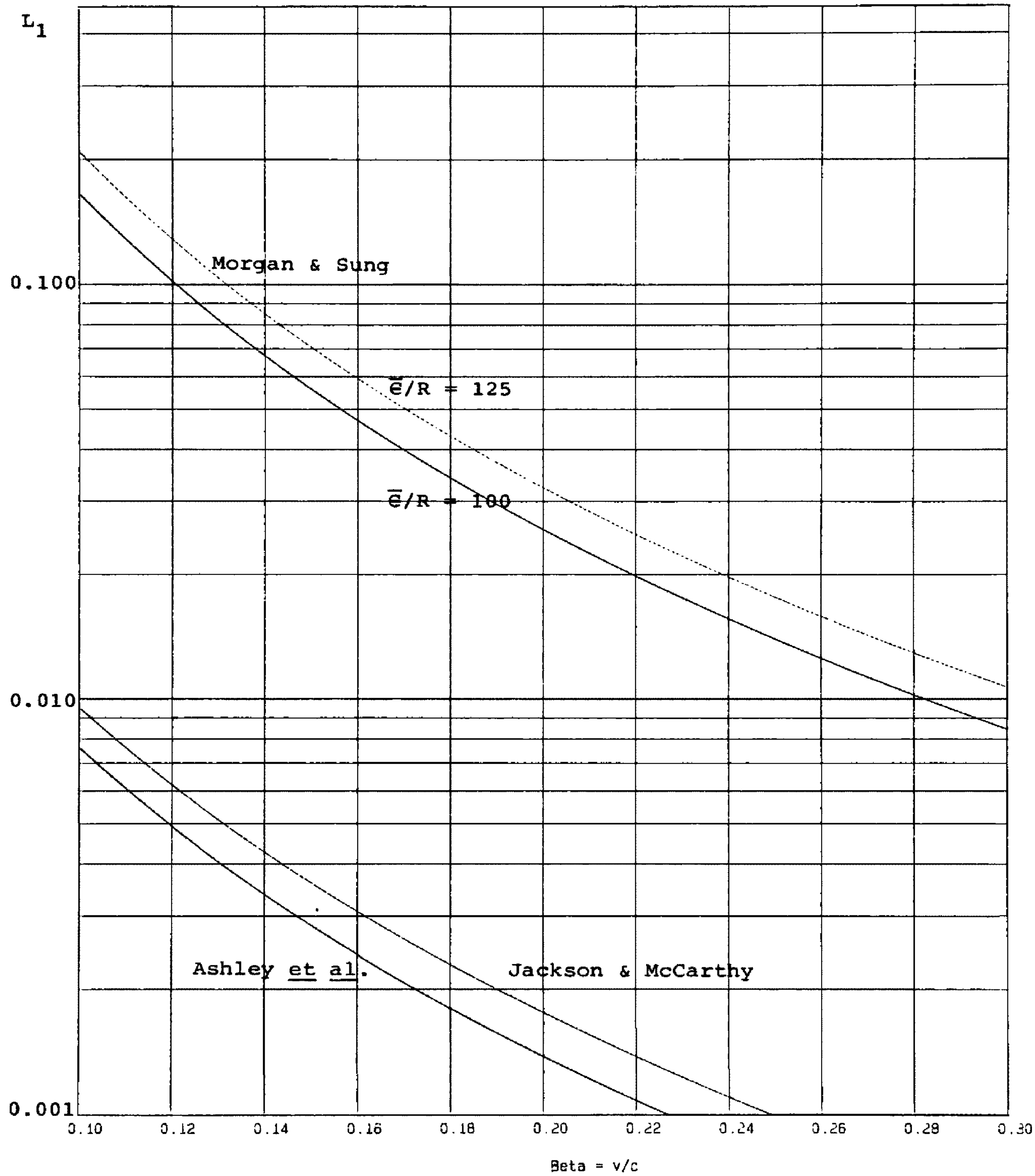


Figure of L_1 vs. Beta for four different calculations (Be)

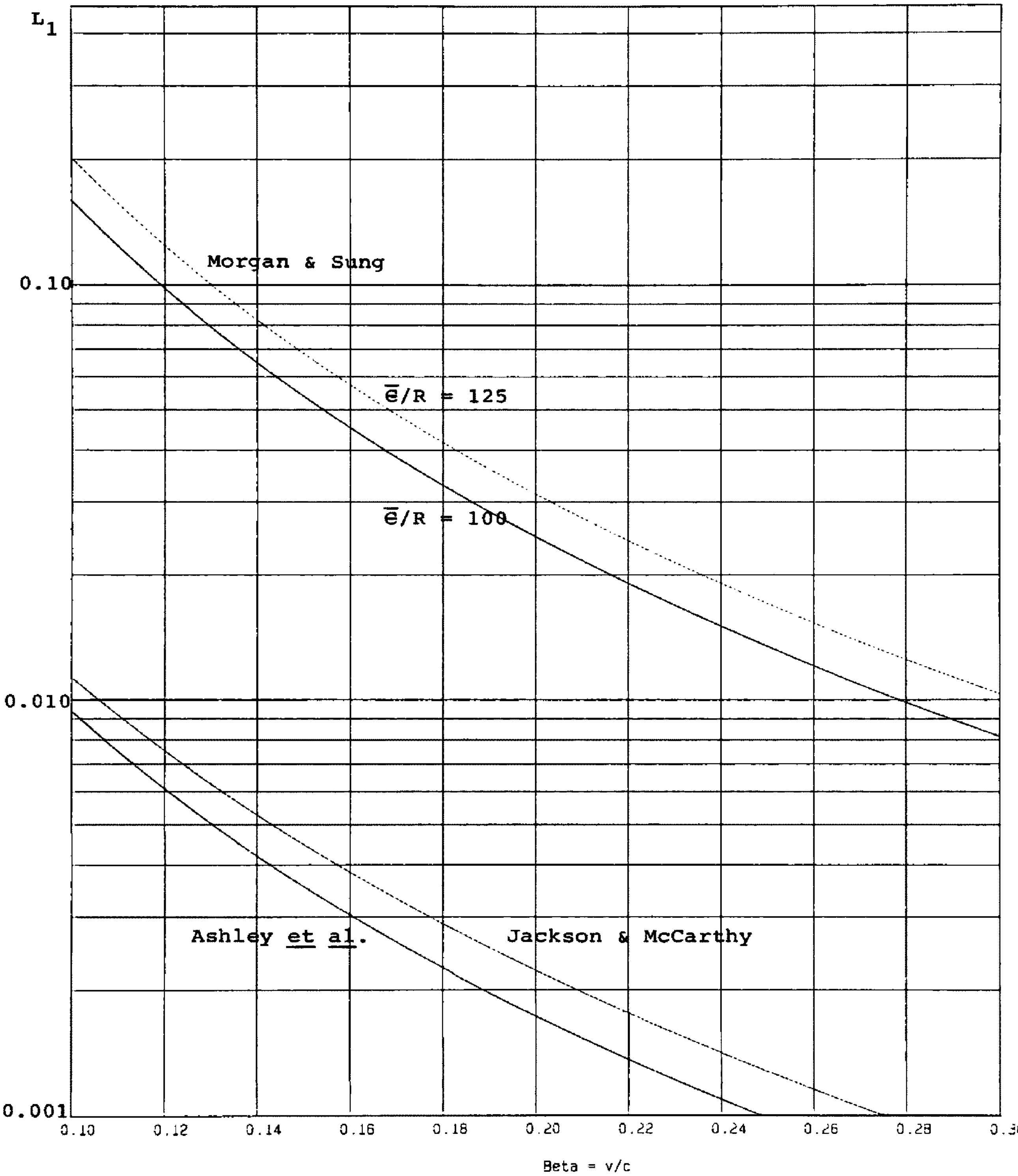


Figure of L_1 vs. Beta for four different calculations (B)

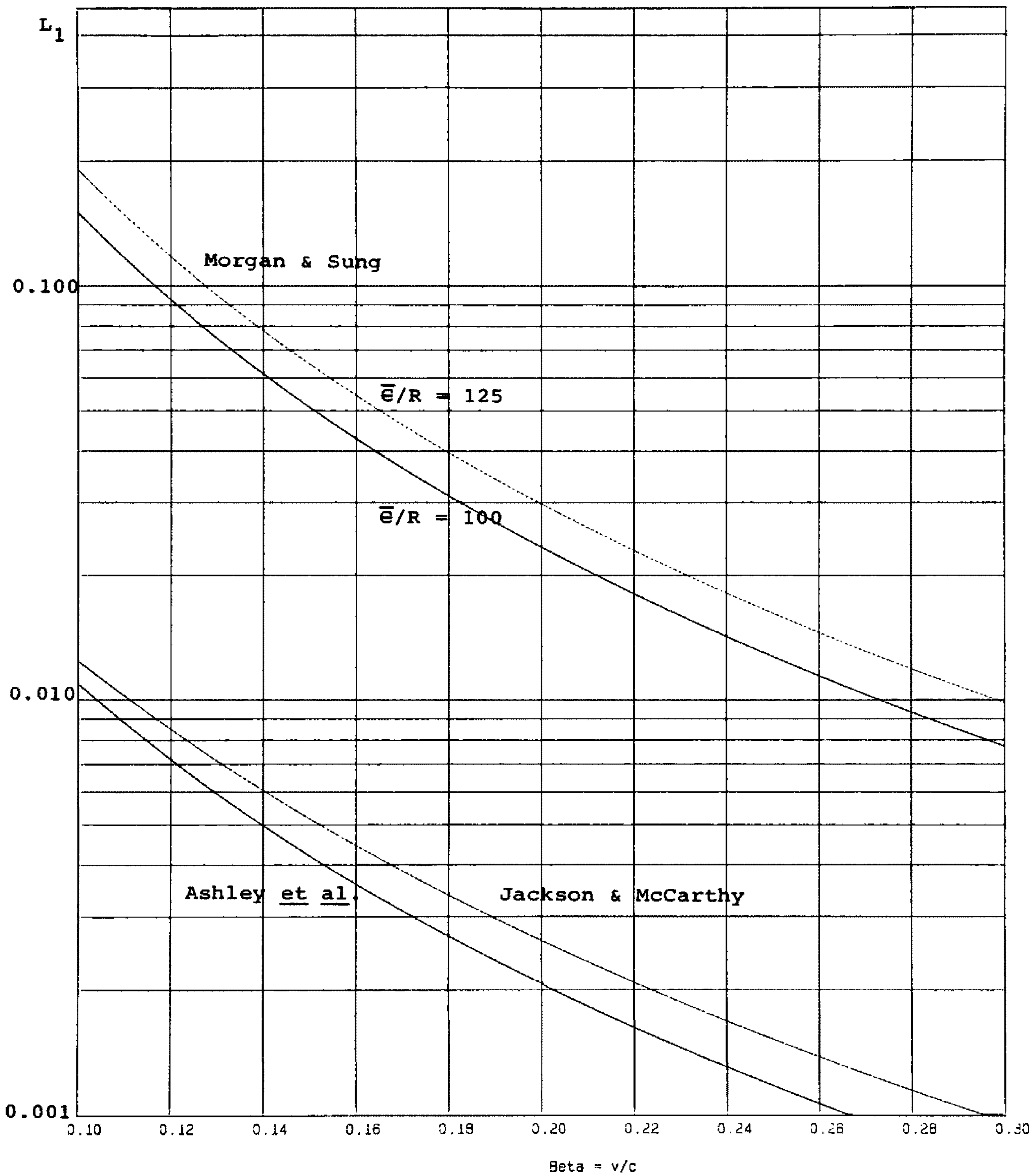


Figure of L_1 vs. Beta for four different calculations (C)

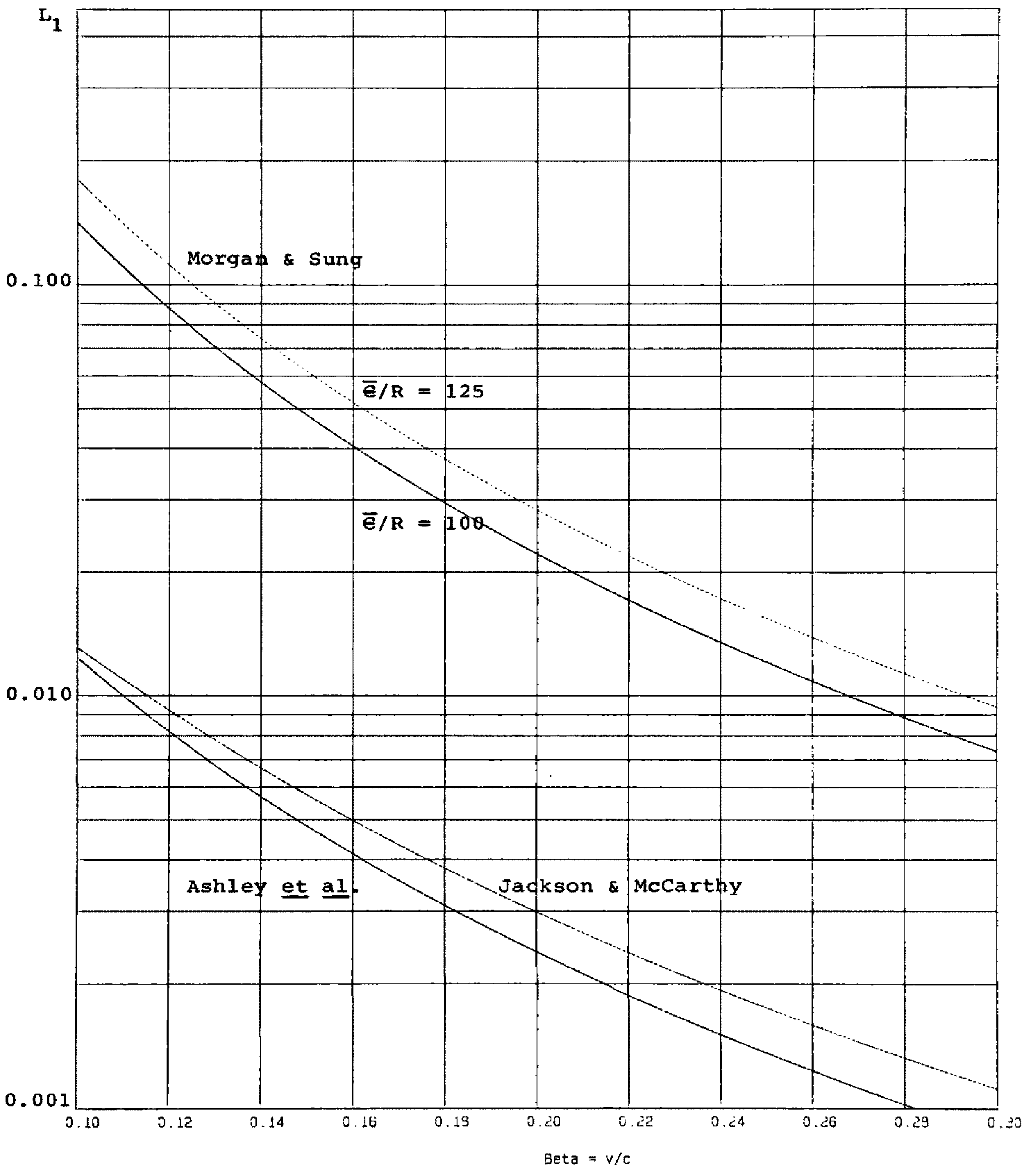


Figure of L_1 vs. Beta for four different calculations (N)

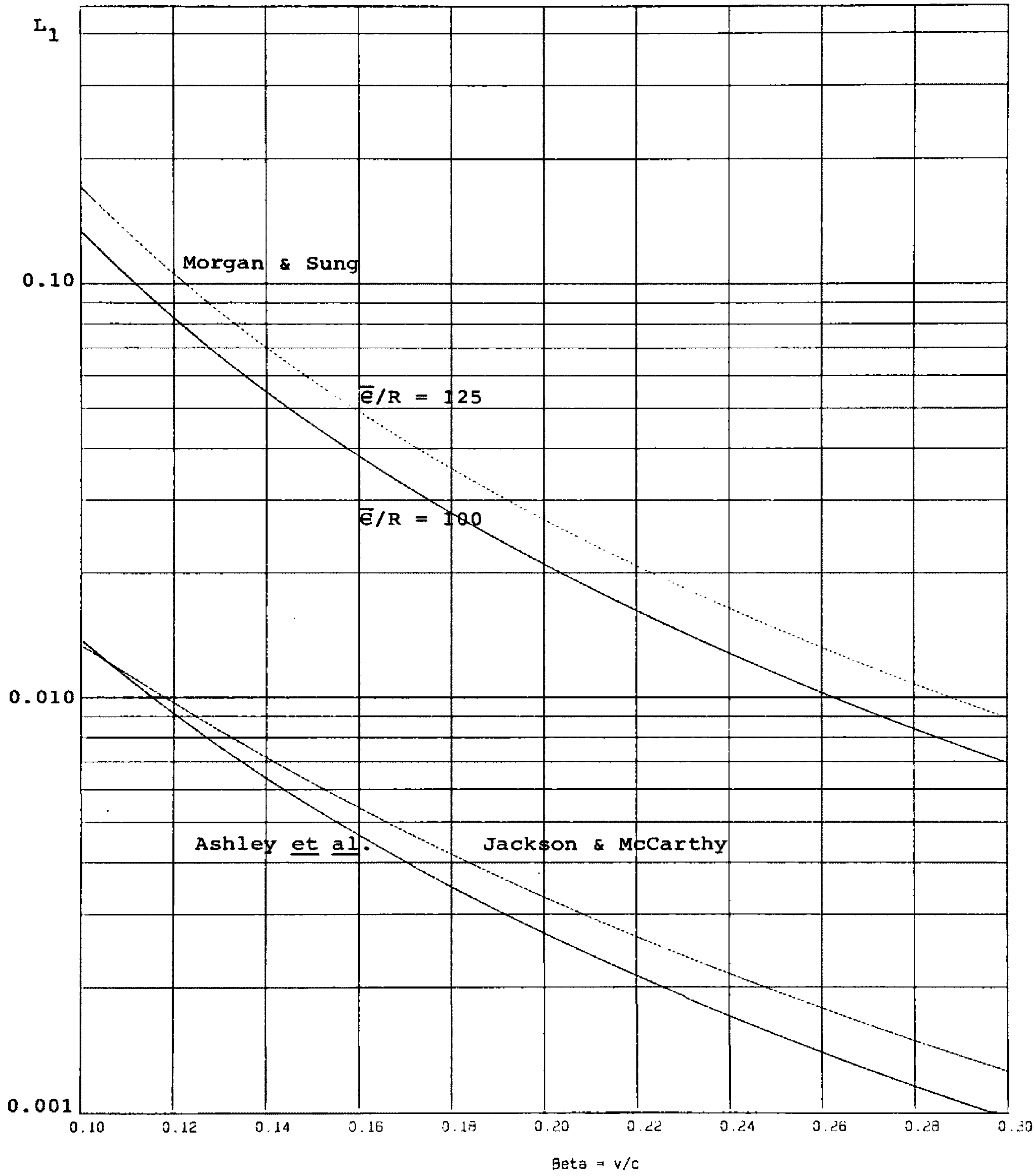


Figure of L_1 vs. Beta for four different calculations (O)

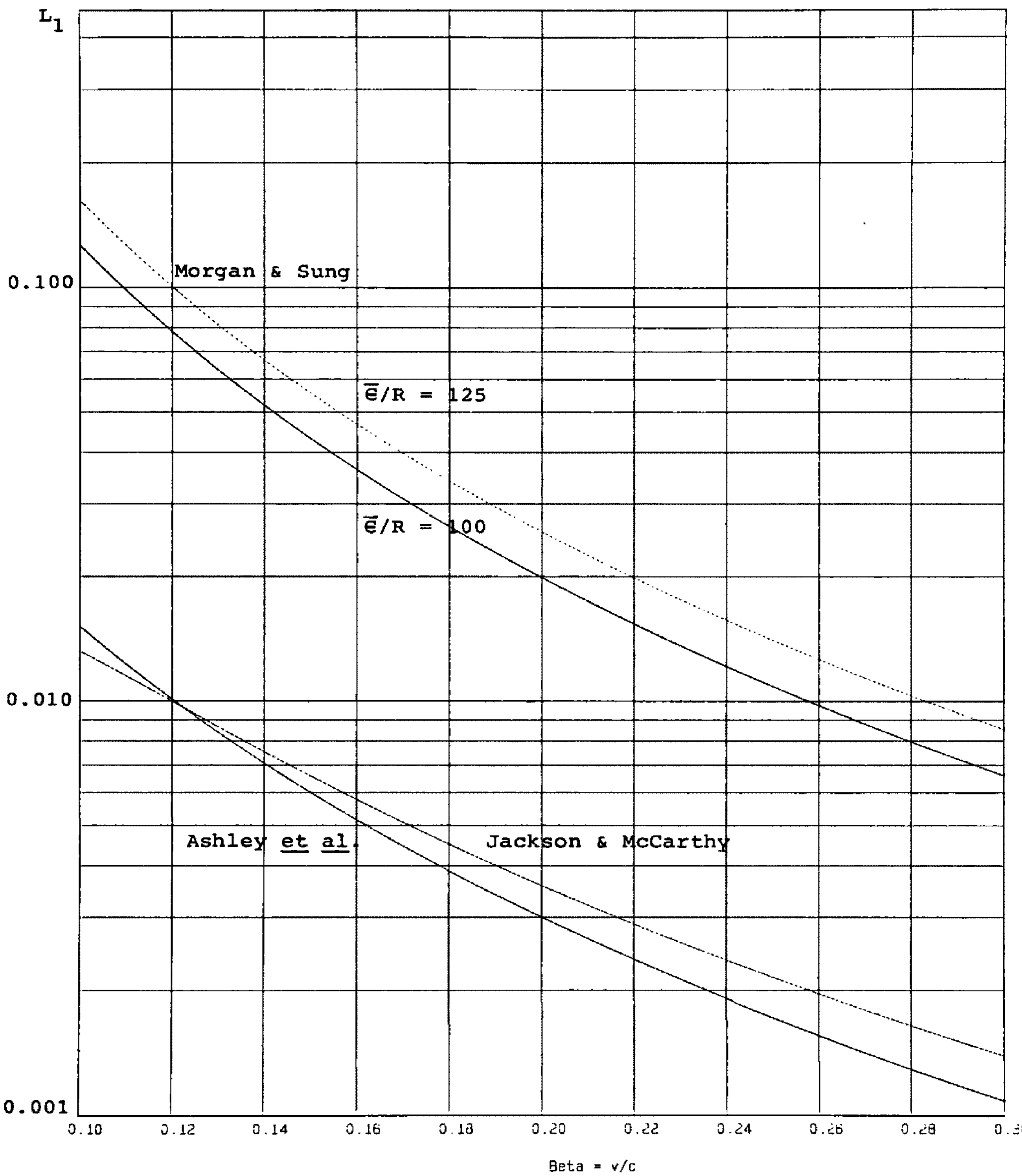


Figure of L_1 vs. Beta for four different calculations (F)

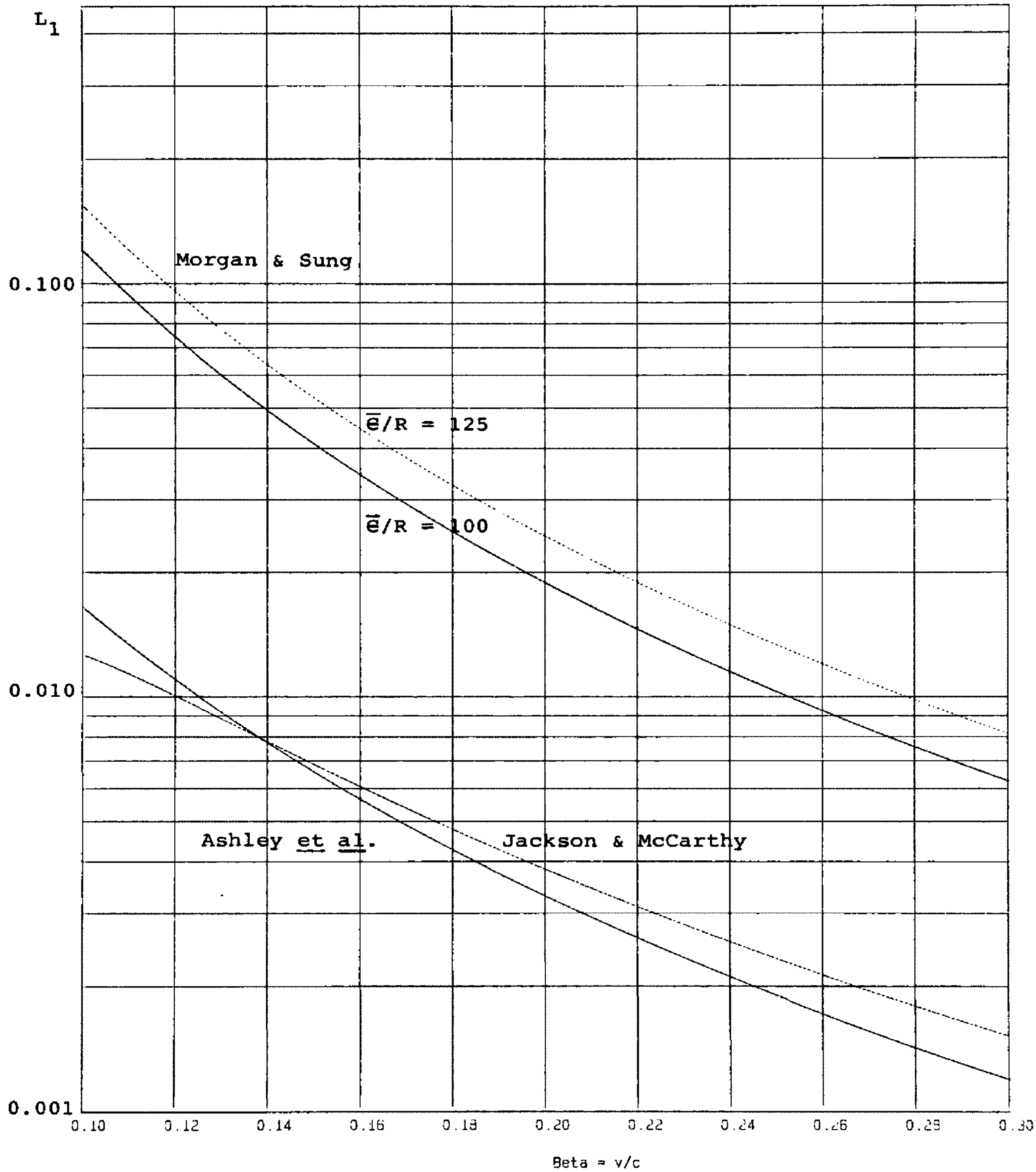


Figure of L_1 vs. Beta for four different calculations (Ne)

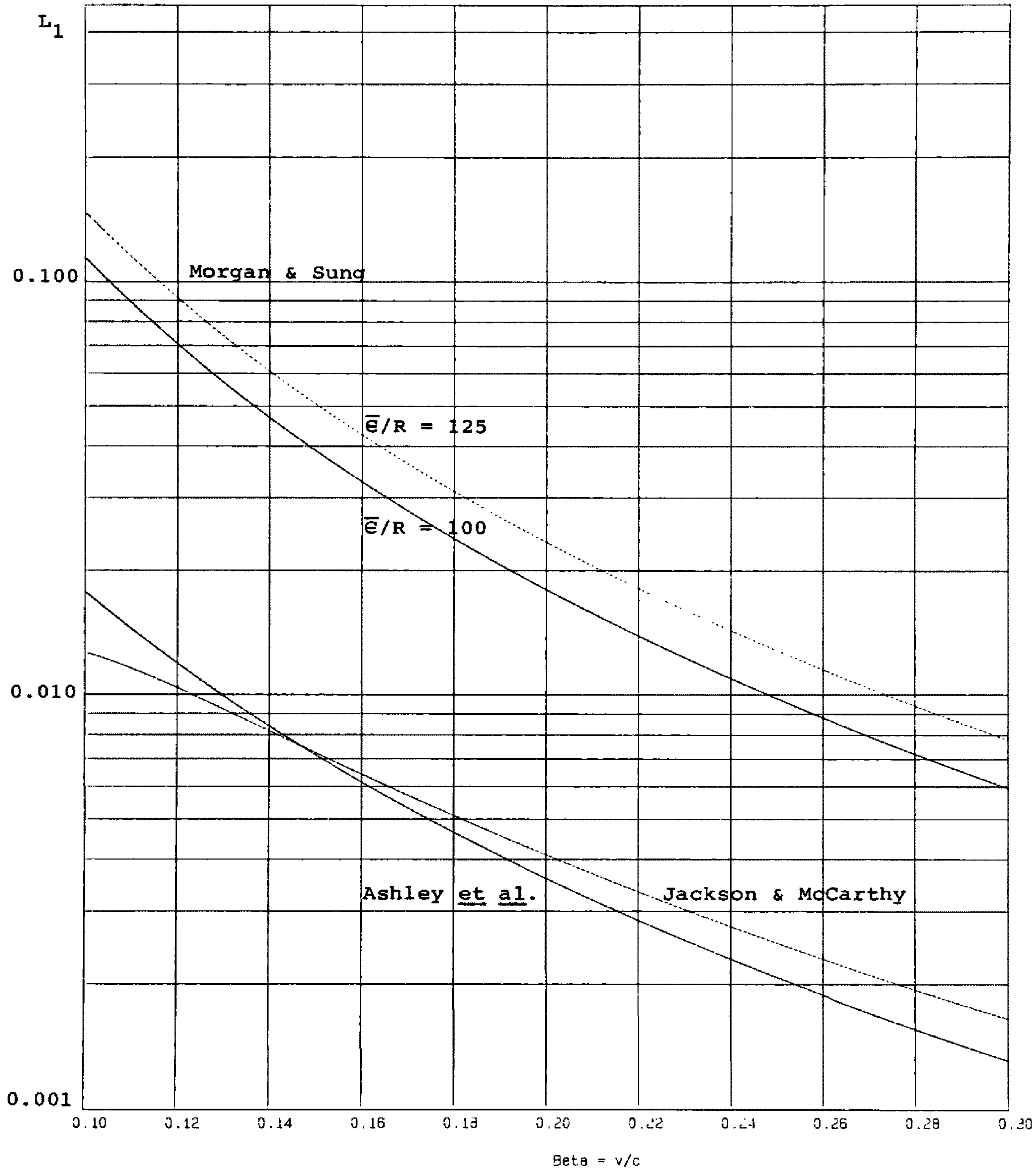


Figure of L_1 vs. Beta for four different calculations (Na)

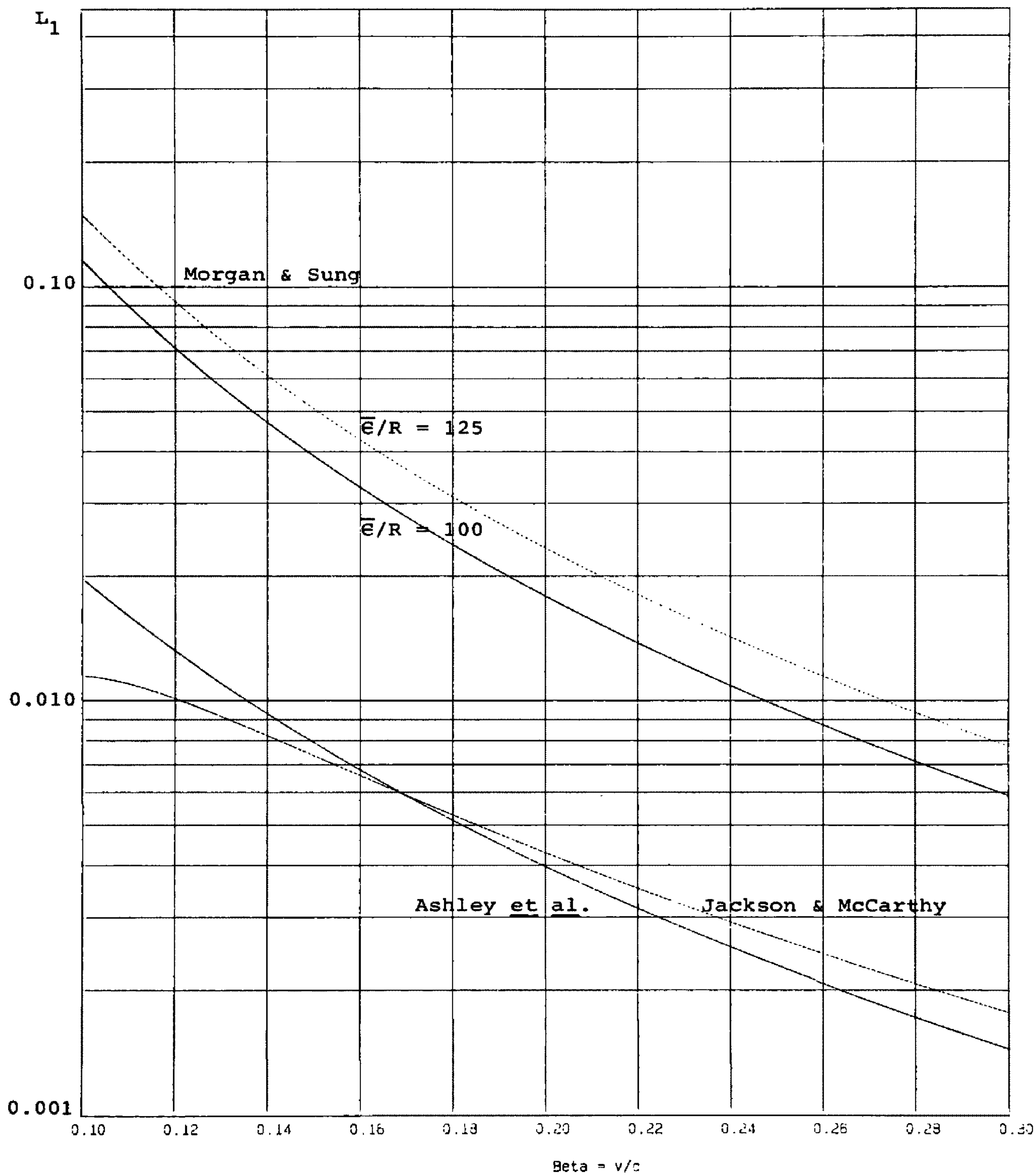


Figure of L_1 vs. Beta for four different calculations (Mg)

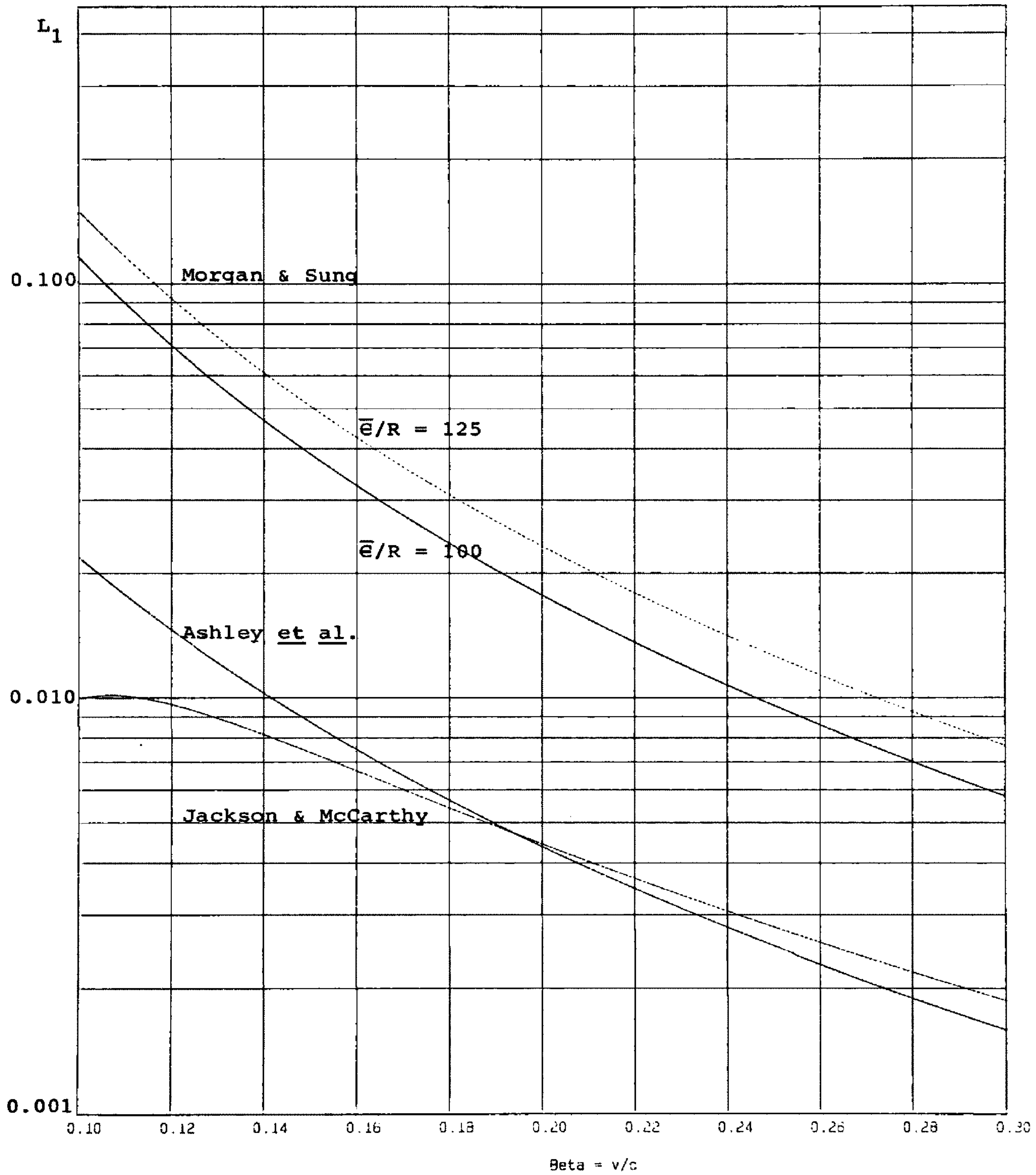


Figure of L_1 vs. Beta for four different calculations (Al)

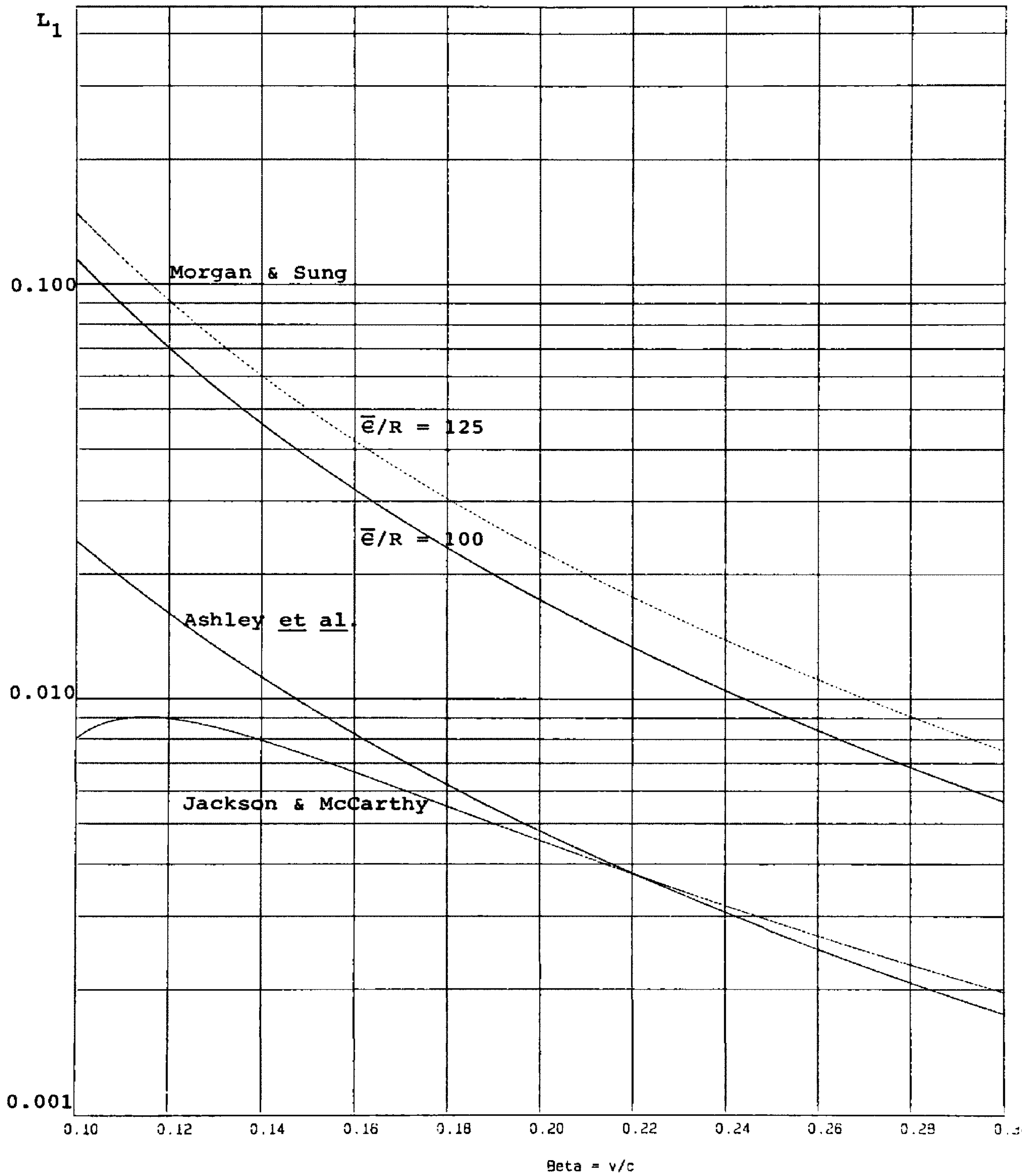


Figure of L_1 vs. Beta for four different calculations (Si)

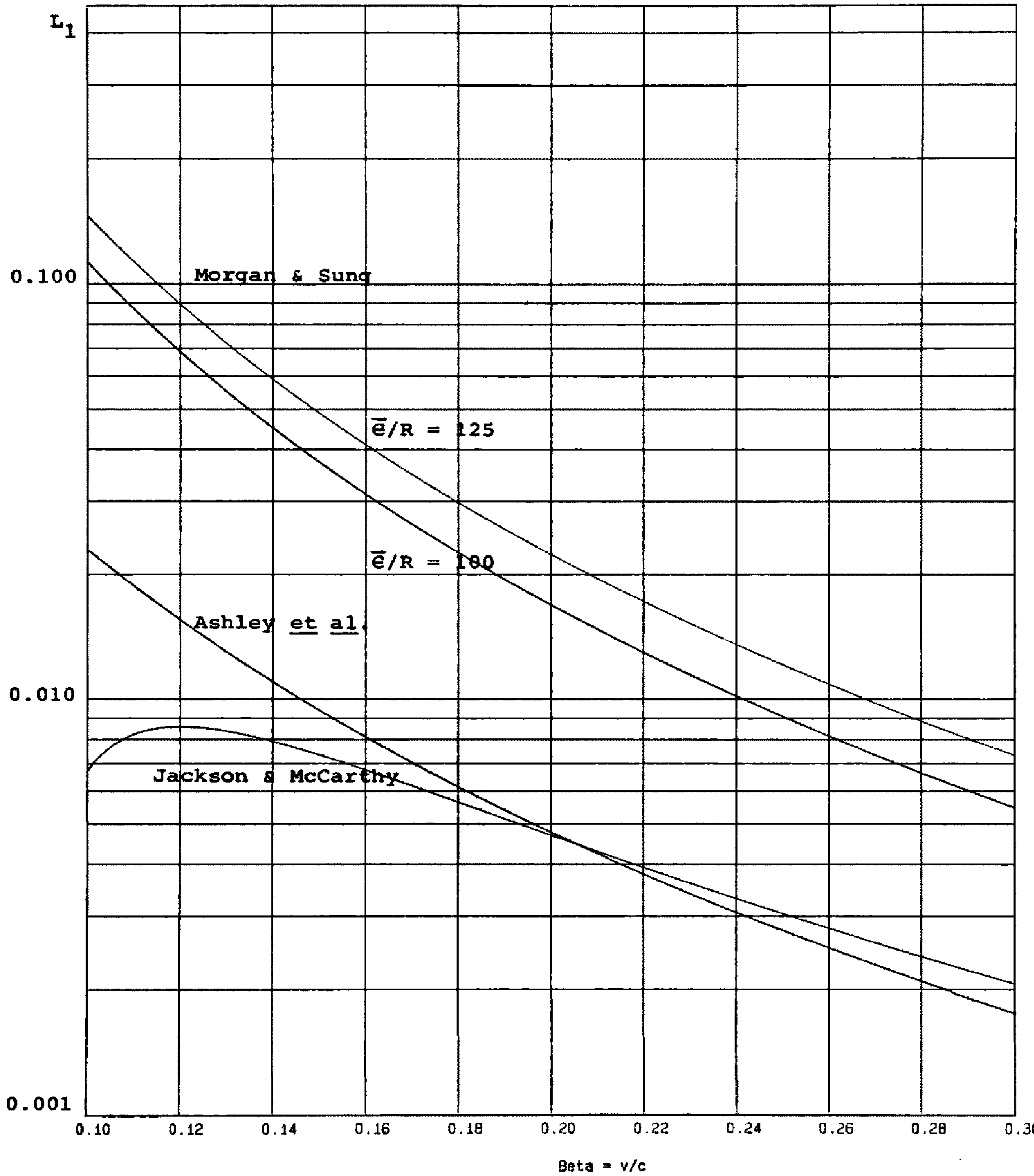


Figure of L_1 vs. Beta for four different calculations (P)

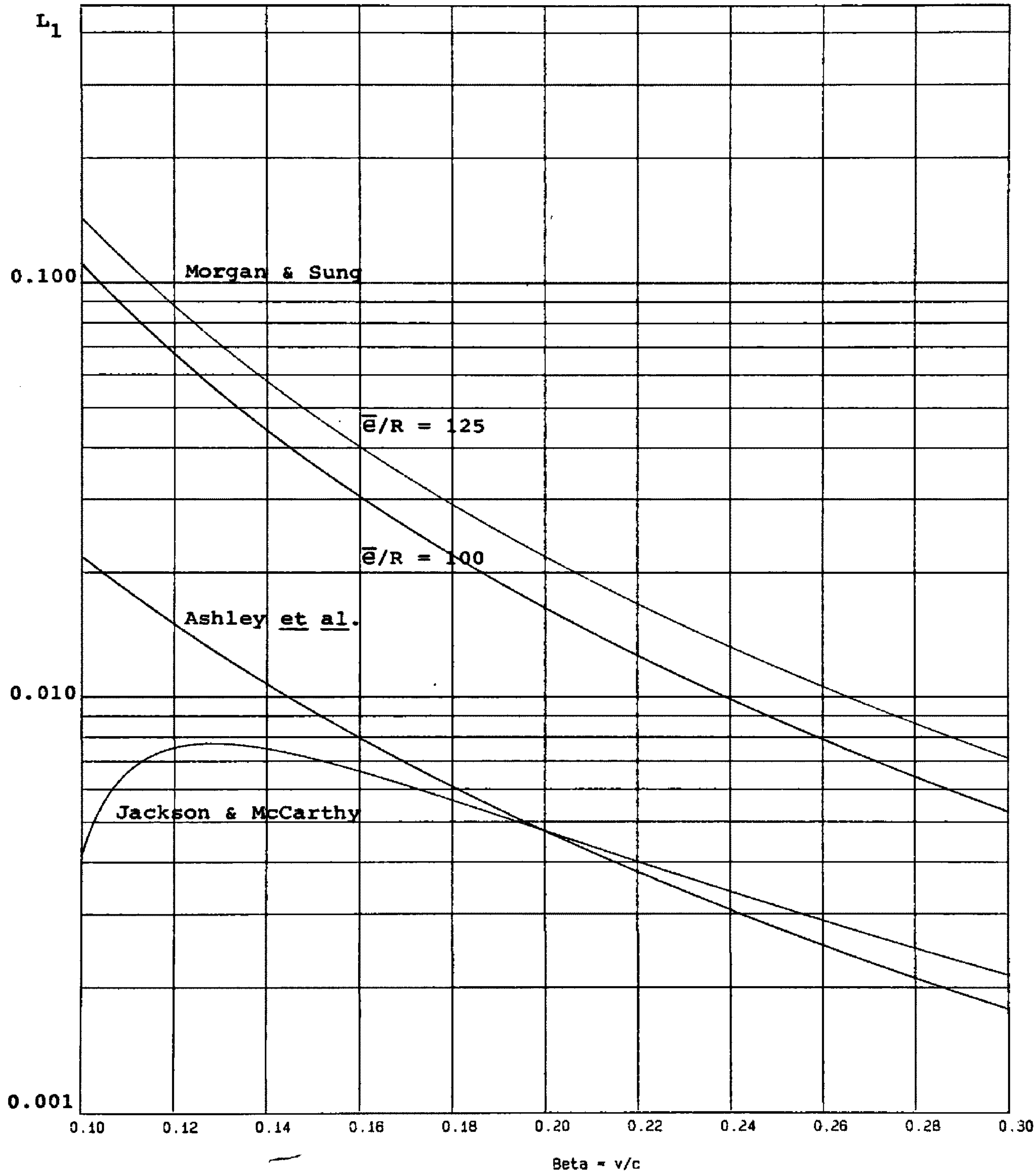


Figure of L_1 vs. Beta for four different calculations (S)

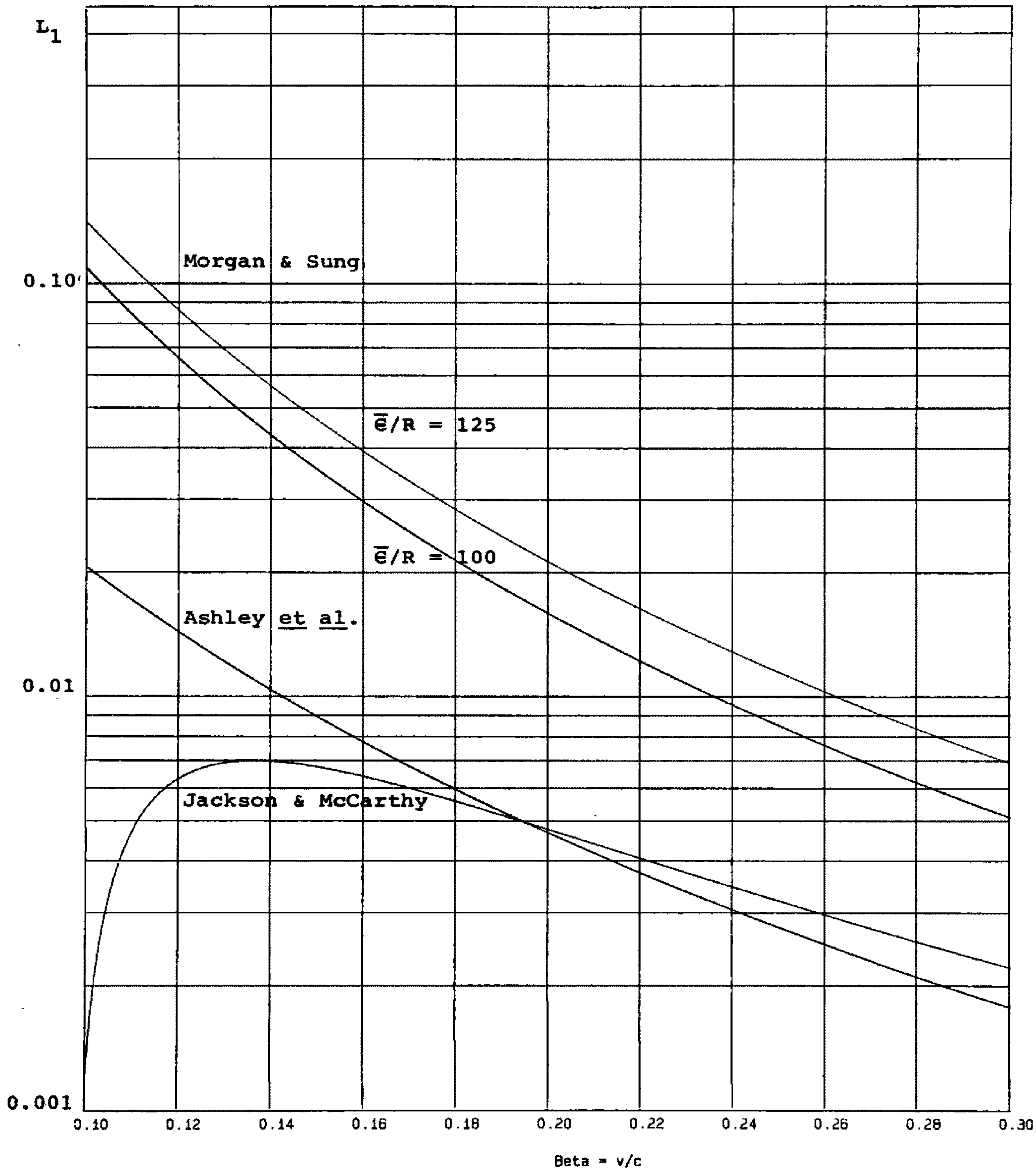


Figure of L_1 vs. Beta for four different calculations (Cl)

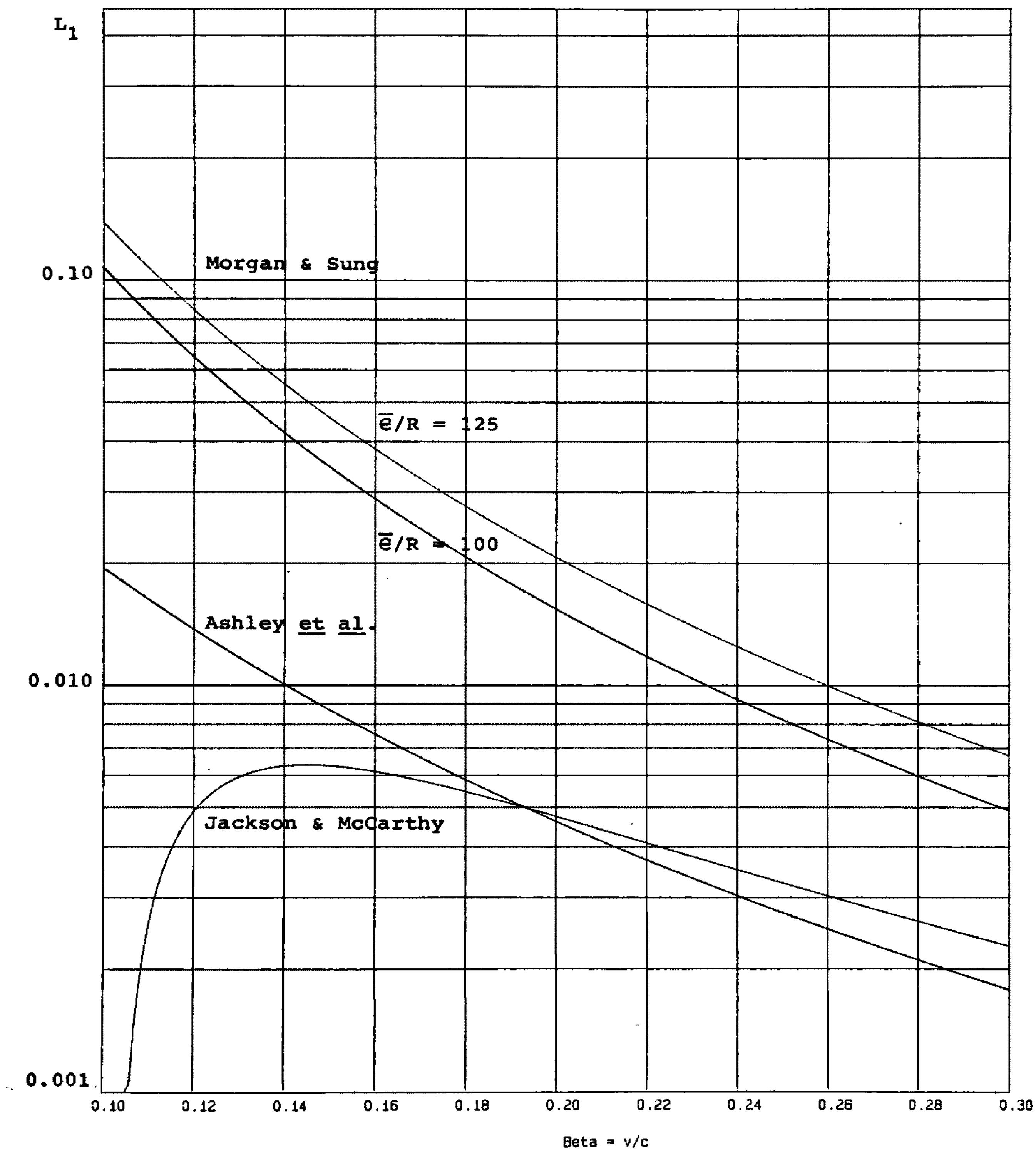
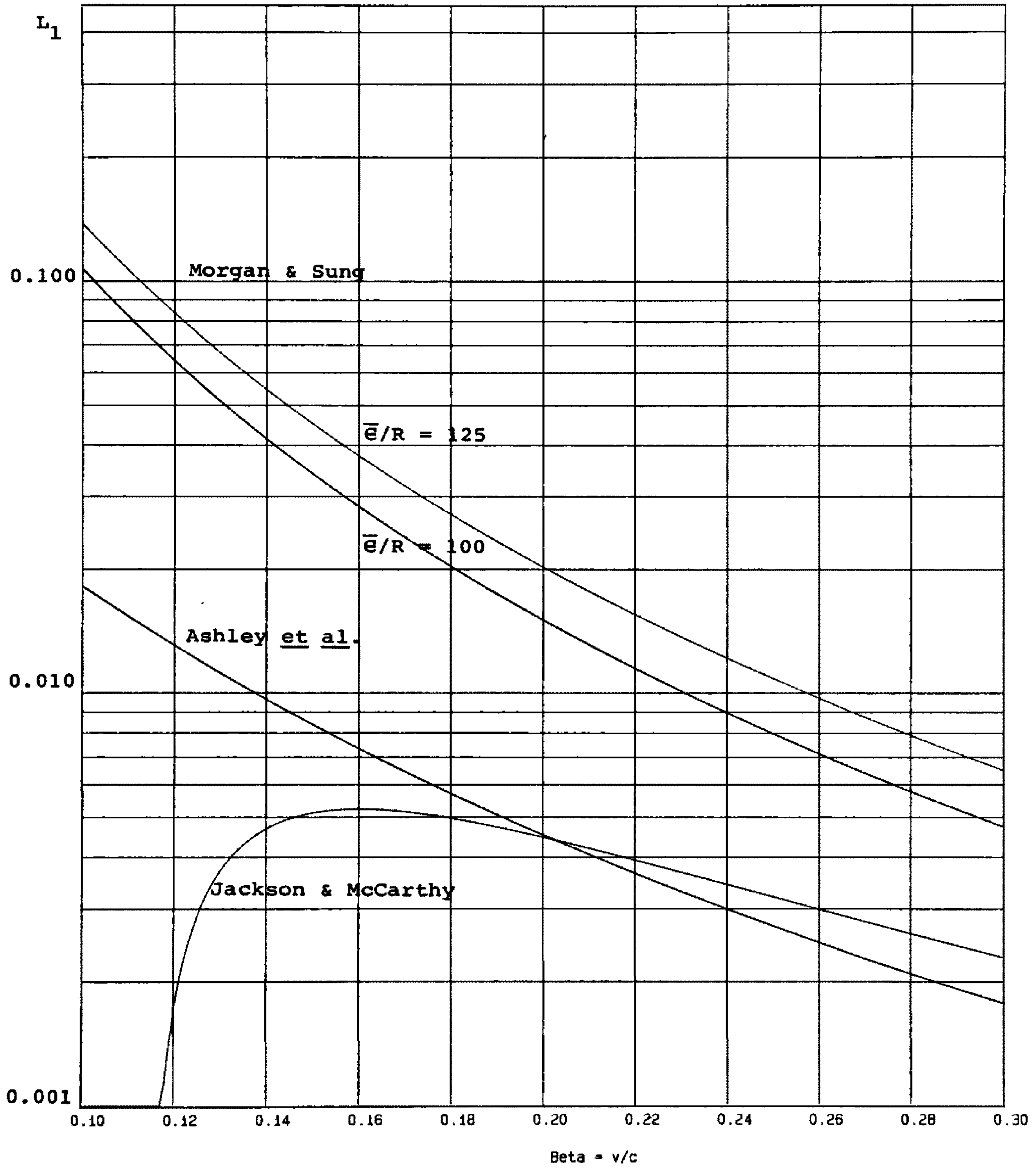


Figure of L_1 vs. Beta for four different calculations (Ar)



CHAPTER V

CONCLUSIONS

One of the major discoveries of this study is that in the low energy range (proton projectile energy lower than 5 MeV, $\beta < 0.1$), the method of J. C. Ashley _et al._, is the best method to use. Both the methods of J. D. Jackson and R. L. McCarthy and of S. H. Morgan and C. C. Sung are not valid.

Another discovery is that in the high energy range (projectile energy between 5.7 MeV and 20.0 Mev, $0.11 < \beta < 0.20$), S. H. Morgan and C. C. Sung's method yields the best fit to the experimental data.

APPENDIX I
COMPUTER CODES

```
      PROGRAM CONVET
      implicit integer*2 (a-z)
        character*36 filnam,fname
        logical*1 filxst
        REAL* 8   MAS(5),ENGj8(5),ENGeV8(5),B8,V8,C,e
        REAL* 4   ENGj4(5),ENGeV4(5),B4,V4
        integer*2 num,b

        filnam(1:14) = 'HON:ENGVEL.TAB'
        filnam(15:15) = char(0)
        call fpath(filnam,fname)
        INQUIRE(FILE = fname, EXIST =filxst)

        if(filxst) then
          OPEN(unit = 1,FILE = fname,STATUS = 'OLD')
          CLOSE(unit = 1,STATUS = 'DELETE')
        ENDIF

        OPEN(unit = 1,FILE = fname,STATUS = 'NEW')

        MAS(1) = 1.67264850-27
        MAS(2) = 4.001505*1.6605655D-27

        C      = 2.99792458D8
        e      = 1.60218920-19

        num = 1
20      B4 = 0.001

10      B8 = B4
        V4 = B8 * C
        ENGj8(num) = MAS(num)*C*C
        ENGj8(num) = ENGj8(num)/SQRT(1.0-B8*B8) -  ENGj8(num)

        ENGj4(num) = ENGj8(num)
        ENGeV4(num)= ENGj8(num)/(e*1000000.0)

        write(1,901)B4,ENGeV4(num),ENGj4(num),V4
901     FORMAT(5X,1F6.3,5X,1F12.6,5X,1E12.6,5X,1E12.6)
        B = NINT(B4*1000.0) + 1
        if(B.gt.300) goto 5
        B4 = FLOAT(B)/1000.0
        goto 10

5       num = num + 1
        if(num.le.2) goto 20
        close(unit = 1)
        end
```

PROGRAM ALANDP

```
      integer*4 n
      parameter(n = 40)
      real*8      sexp(n),s(4,n), dsexp(n),segma(4)
      real*8      beta(n),energy(n),l0,l1(4),l2,l(4)
      real*8      c,m0p,m0a,enery0,w,b,x,mass,e
      integer*4   z2,z1 ,wu(4),lin(4),time

      data sexp(1), sexp(2), sexp(3), sexp(4)
     *     /101.88, 94.65, 88.52, 83.23/
      data energy(1),energy(2),energy(3),energy(4)
     *     /2.25,    2.5,     2.75,     3.0/

      data sexp(5), sexp(6), sexp(7), sexp(8)
     *     /78.61,  74.55,  70.98,  67.72/
      data energy(5),energy(6),energy(7),energy(8)
     *     /3.25, 3.5, 3.75,  4.0/

      data sexp(9), sexp(10), sexp(11), sexp(12)
     *     /64.82,  62.19,  59.78, 57.57 /
      data energy(9),energy(10),energy(11),energy(12)
     *     /4.25,  4.5,  4.75,  5.0/

      data sexp(13), sexp(14), sexp(15), sexp(16)
     *     /55.53,  53.65,  51.90, 50.28/
      data energy(13),energy(14),energy(15),energy(16)
     *     /5.25,  5.5,  5.75,  6.0 /

      data sexp(17), sexp(18), sexp(19), sexp(20)
     *     /47.34,  44.76, 42.48, 40.44/
      data energy(17),energy(18),energy(19),energy(20)
     *     /6.5,  7.0,   7.5,   8.0/

      data sexp(21), sexp(22), sexp(23), sexp(24)
     *     /38.61,  36.96, 35.45,   34.09 /
      data energy(21),energy(22),energy(23),energy(24)
     *     /8.5,  9.0,  9.5,   10.0/

      data sexp(25), sexp(26), sexp(27), sexp(28)
     *     /32.82,  31.67, 30.59,   29.60 /
      data energy(25),energy(26),energy(27),energy(28)
     *     /10.5,  11.0,  11.5,  12.0/

      data sexp(29), sexp(30), sexp(31), sexp(32)
     *     /28.68,  27.82,  27.02,  26.26/
      data energy(29),energy(30),energy(31),energy(32)
     *     /12.5,  13.0,  13.5,  14.0/

      data sexp(33), sexp(34), sexp(35), sexp(36)
     *     /25.56,   24.89,  24.26,  23.67/
      data energy(33),energy(34),energy(35),energy(36)
```

```
     *     /14.5,   15.0,   15.5,   16.0/

       data sexp(37), sexp(38), sexp(39), sexp(40)
     *     /23.11,   22.58, 22.07,   21.59/
       data energy(37),energy(38),energy(39),energy(40)
     *     /16.5,   17.0,   17.5,   18.0       /

          do 100 i = 1,n
            dsexp(i) = dsexp(i)*sexp(i)*0.01
100       continue

          e = 1.6021892d-19
          Z1 = 1
          z2 = 13
          c = 2.99792458d8
          m0p = 1.6726485d-27
          mass = 27.0
          enery0 = m0p*c*c

          wu(1) = 1
          lin(1) = 10
          wu(2) = lin(1) + 1
          lin(2) = 14
          wu(3) = lin(2) + 1
          lin(3) = 40
          time = 1
111           do 20 i = 1,3
             segma(i) = 0.0
20         continue

          do 10 i = wu(time),lin(time)
            energy(i) = energy(i)*e*1.0e6
            beta(i) = sqrt(1.0-(enery0/(energy(i)+enery0))**2
            l0      = fal(beta(i))
            CALL SUBL1(L1,BETA(i),z2)
            l2        = fl2(beta(i),z1)
            do 30 k = 1, 4
              L(k)     = L0 + L1(k)*Z1 + L2
              S(k,i)   =
     *        (0.30708/(BETA(I)*BETA(I)))*Z1*Z1*Z2*L(k)/mass
              segma(k)= segma(k)+((sexp(i)-s(k,i))/s(k,i))**2
30          continue
10        continue

          do 40 k = 1,4
          segma(k)=sqrt(segma(k)/float(lin(time)-wu(time)+1))
40        continue
          write(*,*)segma
          time = time + 1
          if(time.eq.4) goto 112
          goto 111
112       end
```

```
      REAL*8 FUNCTION FAL(v)

      integer*4 n
      parameter (n = 43)
      real*8 w(n),f(n)
      real*8  u, x1, x2, x3, a1, a2, a3 ,v
      real*8  c, malpha,e

      data w(1),     w(2),      w(3),      w(4),      w(5)
     *     /0.4,   0.6,      0.7,      1.0,        1.5/
      data f(1),     f(2),      f(3),      f(4),      f(5)
     *     /0.7753, 0.9295, 1.0015, 1.2145, 1.4888/

      data w(6),     w(7),      w(8),      w(9),      w(10)
     *     /2.0,      2.5,      3.0,       3.18,       3.97/
      data f(6),     f(7),      f(8),      f(9),      f(10)
     *     /1.7252, 1.9267, 2.0999, 2.1564, 2.3770/

      data w(11),    w(12),     w(13),     w(14),     w(15)
     *     /4.77,     5.56,       6.35,       7.15,       7.94/
      data f(11),    f(12),     f(13),     f(14),     f(15)
     *     /2.5635, 2.7209, 2.8582, 2.9811, 3.0901/

      data w(16),   w(17),      w(18),      w(19),      w(20)
     *     /8.74,     9.53,       10.32,       11.12,     11.91/
      data f(16),     f(17),      f(18),      f(19),       f(20)
     *     /3.1902, 3.2806, 3.3637, 3.4418, 3.5136/

      data w(21),      w(22),      w(23),      w(24),      w(25)
     *     /12.71,      13.5,       14.3,        15.09, 15.88/
      data f(21),      f(22),      f(23),      f(24),      f(25)
     *     /3.5818, 3.6451, 3.7055, 3.7622, 3.8160/

      data w(26),      w(27),      w(28),      w(29),      w(30)
     *     /16.68,     17.47,     18.27,      19.06,      19.65/
      data f(26),     f(27),      f(28),      f(29),       f(30)
     *     /3.8681, 3.9168, 3.9639, 4.0084, 4.0511/

      data w(31),     w(32),      w(33)    , w(34), w(35)
     *     /20.65,      21.44,      22.24, 23.84,    27.81/
      data f(31),     f(32),      f(33)    , f(34), f(35)
     *     /4.0928, 4.1325, 4.1712,    4.2443, 4.4072  /

      data w(36),      w(37),      w(38),      w(39),      w(40)
     *     /31.78,     39.73,     47.67,     55.62,     63.56/
      data f(36),     f(37),      f(38),      f(39),       f(40)
     *     / 4.5479, 4.7820,   4.9722,   5.1320, 5.2696/

      data w(41),     w(42),      w(43)
     *     /71.51, 79.45,   87.40/
      data f(41),     f(42),      f(43)
     *     /5.3899,   5.4968,   5.5931/
```

```
      malpha = 4.001505*1.6605655E-27
      e = 1.6021892E-19
      c = 2.99792458E+8
      u = (malpha*c*c/sqrt(1.0-v*v) - malpha*c*c)/(1.0e6*e)

      do 5 i = 2, n-1
        if(u.le.w(i)) goto 15
5     continue

      i = n-1
      goto 70

15    if(i.eq.2) goto 70

      if((u-w(i-1)).lt.(w(i)-u)) i = i-1

70    x1 = w(i-1)
      x2 = w(i)
      x3 = w(i+1)

      a1 = (u-x2)*(u-x3)/((x1-x2)*(x1-x3))
      a2 = (u-x1)*(u-x3)/((x2-x1)*(x2-x3))
      a3 = (u-x1)*(u-x2)/((x3-x1)*(x3-x2))

      fal = a1*f(i-1) + a2*f(i) +a3*f(i+1)

      return
      end
```

```
      SUBROUTINE SUBL1(L1,B4,NUM)

      REAL* 8   b8,y8,j8,z8,a8,12,121
      REAL* 8   PI,X,W,FW,B(18),X0
      REAL* 8   c,e,R,Mass
      REAL* 8   ENGj4(5),ENGeV4(5),B4,V4
      REAL* 8   S(0:1,18),L(0:1,18),L1(4),a
      REAL* 8   EPR
      integer*4 num

      data S(0,1),S(0,2),S(0,3),S(0,4),S(0,5),S(0,6)
     *     /1.000, 1.999, 3.000, 4.000, 4.999, 5.999/
      data S(0,7),S(0,8),S(0,9),S(0,10),S(0,11),S(0,12)
     *     /7.000, 8.001, 9.003, 10.000, 11.000, 12.000/
      data S(0,13),S(0,14),S(0,15),S(0,16),S(0,17),S(0,18)
     *     /13.000, 14.000, 15.02,  16.01,  17.01,  18.02/

      data S(1,1),S(1,2),S(1,3),S(1,4),S(1,5),S(1,6)
     *     /1.333, 7.709, 21.22, 40.89, 67.34, 101.2/
      data S(1,7),S(1,8),S(1,9),S(1,10),S(1,11),S(1,12)
     *     /143.0, 173.6, 253.9, 316.0,  395.0,  482.4/
      data S(1,13),S(1,14),S(1,15),S(1,16),S(1,17),S(1,18)
     *     /580.8,  679.9,  798.6,  928.9,  1072.0, 1259.0/

      data L(0,1),L(0,2),L(0,3),L(0,4),L(0,5),L(0,6)
     *     /1.500, 2.097, 2.749, 4.173, 6.407, 9.101/
      data L(0,7),L(0,8),L(0,9),L(0,10),L(0,11),L(0,12)
     *     /12.12, 15.42, 18.96, 22.67,  24.27,  26.25/
      data L(0,13),L(0,14),L(0,15),L(0,16),L(0,17),L(0,18)
     +     /28.76,  31.76,  35.09,  38.63,  42.32,  46.22/

      data L(1,1),L(1,2),L(1,3),L(1,4),L(1,5),L(1,6)
     *     /7.612, 13.67, 56.10, 129.7, 240.4, 393.7/
      data L(1,7),L(1,8),L(1,9),L(1,10),L(1,11),L(1,12)
     *     /594.5, 850.5, 1169.0,1488.0, 1930.0, 2433.0/
      data L(1,13),L(1,14),L(1,15),L(1,16),L(1,17),L(1,18)
     *     /3015.0, 3591.0, 4322.0, 5143.0, 6062.0, 7370.0/

      data B(1),  B(2),  B(3),  B(4),  B(5),  B(6)
     *     /1.9,   1.87,  1.84,  1.81,  1.78,  1.76 /
      data B(7),  B(8),  B(9),  B(10), B(11), B(12)
     *     /1.73,  1.70,  1.67,  1.64,  1.55,  1.46 /
      data B(13), B(14), B(15), B(16), B(17), B(18)
     *     /1.37,  1.52,  1.66,  1.81,  1.95,  2.1   /

      PI = 3.14159265
      e = 1.60218920-19
      c = 2.99792458D8
      R = 13.605804*e
      Mass = 9.109534D-31
 10   B8 = B4
      X  = 137.03604*B8
```

```
      XO  =  X*X/FLOAT(NUM)
      W   =  B(NUM)/SQRT(XO)
      L1(1)  =  FW(W)/SQRT(FLOAT(NUM)*xO*xO*xO)

      L1(2)  =  3.0*PI*S(1,NUM)/(8.0*X*X*X*S(0,NUM))*
     *          (DLOG(2.0*mass*(B8*C)*(B8*C)/R)
     *          - L(1,NUM)/S(1,NUM)  - 1.04)

      EPR  =  100.0
      L1(3)  =  PI*S(1,NUM)/(4.0*X*X*X*S(0,NUM))*
     *  ((EPR*S(0,NUM)/S(1,NUM)-1)
     *  *dlog(2.0*mass*(b8*c)*(b8*c)/r)
     *  - EPR*L(0,NUM)/S(1,NUM)  + L(1,NUM)/S(1,NUM))

      EPR  =  125.0
      L1(4)  =  PI*S(1,NUM)/(4.0*X*X*X*S(0,NUM))*
     *  ((EPR*S(0,NUM)/S(1,NUM)-1)
     *  *dlog(2.0*mass*(b8*c)*(b8*c)/r)
     *  - EPR*L(0,NUM)/S(1,NUM)  + L(1,NUM)/S(1,NUM))

      RETURN
      end
```

```
      REAL * 8 FUNCTION FL2(B8,z1)

      REAL * 8    b8,y8,j8,z8,a8,l2,l21
      REAL * 8    ENGj4(5),ENGeV4(5),B4,V4
      integer*4  z1

      a8 = 7.2973503D-3
      z8 = sqrt(float(z1))
      y8 = z8 * a8 / b8
      l2 = 0.0

      j = 1
50    j8 = float(j)
      if(j8.gt.1000.0*y8) goto 40
      l2 = l2 - y8*y8/(j8*(j8*j8+y8*y8))
      j = j + 1
      goto 50

40     l21 = - y8*y8*(1.20206 - y8*y8*(1.042 - 0.8541*y8*y8
     *         + 0.343*y8*y8*y8*y8))
      fl2 = l2
      return
      end
```

```
REAL*8 FUNCTION FW(u)

integer*4 n
parameter (n = 200)
real*8 w(n),f(n)
real*8  u, x1, x2, x3, a1, a2, a3

      data w(1),     w(2),     w(3),     w(4),     w(5)
     *    /0.02,     0.07,     0.12,     0.17,     0.22    /
      data f(1),     f(2),     f(3),     f(4),     f(5)
     *    /16.7600, 11.5674, 9.31077, 7.85030, 6.77364/

      data w(6),     w(7),     w(8),     w(9),     w(10)
     *    /0.27,     0.32,     0.37,     0.42,     0.47    /
      data f(6),     f(7),     f(8),     f(9),     f(10)
     *    /5.92643, 5.23446, 4.65510, 4.16182, 3.73662/

      data w(11),    w(12),    w(13),    w(14),    w(15)
     *    /0.52,     0.57,     0.62,     0.67,     0.72    /
      data f(11),    f(12),    f(13),    f(14),    f(15)
     *    /3.36648, 3.04181, 2.75536, 2.50137, 2.27523/

      data w(16),    w(17),    w(18),    w(19),    w(20)
     *    /0.77,     0.82,     0.87,     0.92,     0.97    /
      data f(16),    f(17),    f(18),    f(19),    f(20)
     *    /2.07322, 1.89219, 1.72957, 1.58313, 1.45100/

      data w(21),    w(22),    w(23),    w(24),    w(25)
     *    /1.02,     1.07,     1.12,     1.17,     1.22    /
      data f(21),    f(22),    f(23),    f(24),    f(25)
     *    /1.33170, 1.22362, 1.12560, 1.03654, 0.955494/

      data w(26),    w(27),    w(28),    w(29),    w(30)
     *    /1.27,     1.32,     1.37,     1.42,     1.47    /
      data f(26),    f(27),    f(28),    f(29),    f(30)
     *    /0.881714,0.814493,0.753135,0.697056,0.645755/

      data w(31),    w(32),    w(33),    w(34),    w(35)
     *    /1.52,     1.57,     1.62,     1.67,     1.72    /
      data f(31),    f(32),    f(33),    f(34),    f(35)
     *    /0.596821,0.555813,0.516355,0.480117,0.446833/

      data w(36),    w(37),    w(38),    w(39),    w(40)
     *    /1.77,     1.82,     1.87,     1.92,     1.97    /
      data f(36),    f(37),    f(38),    f(39),    f(40)
     *    /0.416230,0.383109,0.362180,0.338287,0.31617/

      data w(41),    w(42),    w(43),    w(44),    w(45)
     *    /2.02,     2.07,     2.12,     2.17,     2.22    /
      data f(41),    f(42),    f(43),    f(44),    f(45)
     *    /0.295806,0.276937,0.259470,0.243340,0.228351/
```

```
      data w(46),    w(47),    w(48),    w(49),    w(50)
     *     /2.27,     2.32,     2.37,     2.42,     2.47    /
      data f(46),    f(47),    f(48),    f(49),    f(50)
     *     /0.214482,0.201603,0.189629,0.173532,0.163189/

      data w(51),    w(52),    w(53),    w(54),    w(55)
     *     /2.52,     2.57,     2.62,     2.67,     2.72    /
      data f(51),    f(52),    f(53),    f(54),    f(55)
     *     /0.158573,0.149621,0.141266,0.133491,0.126223/

      data w(56),    w(57),    w(58),    w(59),    w(60)
     *     /2.77,     2.82,     2.87,     2.92,     2.97    /
      data f(56),    f(57),    f(58),    f(59),    f(60)
     *     /0.119437,0.113096,0.107166,0.101623,0.096428/

      data w(61),    w(62),    w(63),    w(64),    w(65)
     *     /3.02,     3.07,     3.12,     3.17,     3.22    /
      data f(61),    f(62),    f(63),    f(64),    f(65)
     *     /.0913568,.0869954,.0827097,.0786885,.0749096/

      data w(66),    w(67),    w(68),    w(69),    w(70)
     *     /3.27,     3.32,     3.37,     3.42,     3.47    /
      data f(66),    f(67),    f(68),    f(69),    f(70)
     *     /.0713554,.0680254,.0648858,.0619138,.0591194/

      data w(71),    w(72),    w(73),    w(74),    w(75)
     *     /3.52,     3.57,     3.62,     3.67,     3.72    /
      data f(71),    f(72),    f(73),    f(74),    f(75)
     *     /.0564862,.0539924,.0516426,.0494272,.0473280/

      data w(76),    w(77),    w(78),    w(79),    w(80)
     *     /3.77,     3.82,     3.87,     3.92,     3.97    /
      data f(76),    f(77),    f(78),    f(79),    f(80)
     *     /.0453375,.0434603,.0416608,.0399893,.0383907/

      data w(81),    w(82),    w(83),    w(84),    w(85)
     *     /4.02,     4.07,     4.12,     4.17,     4.22    /
      data f(81),    f(82),    f(83),    f(84),    f(85)
     *     /.0368742,.0354307,.0340620,.0327630,.0315255/

      data w(86),    w(87),    w(88),    w(89),    w(90)
     *     /4.27,     4.32,     4.37,     4.42,     4.47    /
       data f(86),    f(87),    f(88),    f(89),    f(90)
     *     /.0303482,.0292294,.0281635,.0271466,.0261793/

      data w(91),    w(92),    w(93),    w(94),    w(95)
     *     /4.52,     4.57,     4.62,     4.67,     4.72    /
      data f(91),    f(92),    f(93),    f(94),    f(95)
     *     /.0252565,.0243742,.0235340.,0227312,.0219636/

      data w(96),    w(97),    w(98),    w(99),    w(100)
     *     /4.77,     4.82,     4.87,     4.92,     4.97    /
```

```
      data f(96),    f(97),    f(98),    f(99),    f(100)
     *     /.0212299,.0205291,.0198579,.0192152,.0186004/

      data w(101),   w(102),   w(103),   w(104),   w(105)
     *     /5.02,     5.07,     5.12,     5.17,     5.22   /
      data f(101),   f(102),   f(103),   f(104),   f(105)
     *     /.0180112,.0174462,.0169050,.0163859,.0158871/

      data w(106),   w(107),   w(108),   w(109),   w(110)
     *     /5.27,     5.32,     5.37,     5.42,     5.47   /
      data f(106),   f(107),   f(108),   f(109),   f(110)
     *     /.0154090,.0149497,.0145082,.0140840,.0136764/

      data w(111),   w(112),   w(113),   w(114),   w(115)
     *     /5.52,     5.57,     5.62,     5.67,     5.72   /
      data f(111),   f(112),   f(113),   f(114),   f(115)
     *     /.0132842,.0129065,.0125436,.0121940,.0118571/

      data w(116),   w(117),   w(118),   w(119),   w(120)
     *     /5.77,     5.82,     5.87,     5.92,     5.97   /
      data f(116),   f(117),   f(118),   f(119),   f(120)
     *     /.0115327,.0112201,.0109186,.0106278,.0103474/

      data w(121),   w(122),   w(123),   w(124),   w(125)
     *     /6.02,     6.07,     6.12,     6.17,     6.22   /
      data f(121),   f(122),   f(123),   f(124),   f(125)
     *     /.0100767,.0098153,.0095630,.0093194,.0090839/

      data w(126),   w(127),   w(128),   w(129),   w(130)
     *     /6.27,     6.32,     6.37,     6.42,     6.47   /
      data f(126),   f(127),   f(128),   f(129),   f(130)
     *     /.0088564,.0086364,.0084235,.0082177,.0080166/

      data w(131),   w(132),   w(133),   w(134),   w(135)
     *     /6.52,     6.57,     6.62,     6.67,     6.72   /
      data f(131),   f(132),   f(133),   f(134),   f(135)
     *     /.0078259,.0076394,.0074588,.0072843,.0071149/

      data w(136),   w(137),   w(138),   w(139),   w(140)
     *     /6.77,     6.82,     6.87,     6.92,     6.97   /
      data f(136),   f(137),   f(138),   f(139),   f(140)
     *     /.0069507,.0067916,.0066373,.0064877,.0063424/

      data w(141),   w(142),   w(143),   w(144),   w(145)
     *     /7.02,     7.07,     7.12,     7.17,     7.22   /
      data f(141),   f(142),   f(143),   f(144),   f(145)
     *     /.0062014,.0060644,.0059315,.0058024,.0056768/

      data w(146),   w(147),   w(148),   w(149),   w(150)
     *     /7.27,     7.32,     7.37,     7.42,     7.47   /
      data f(146),   f(147),   f(148),   f(149),   f(150)
```

```
*      /.0055550,.0054363,.0053212,.0052094,.0051007/

  data w(151),  w(152),  w(153),  w(154),  w(155)
*      /7.52,     7.57,     7.62,     7.67,     7.72    /
  data f(151),  f(152),  f(153),  f(154),  f(155)
*      /.0049951,.0048924,.0047925,.0046953,.0046007/

  data w(156),  w(157),  w(158),  w(159),  w(160)
*      /7.77,     7.82,     7.87,     7.92,     7.97    /
  data f(156),  f(157),  f(158),  f(159),  f(160)
*      /.0045086,.0044191,.0043316,.0042466,.0041638/

  data w(161),  w(162),  w(163),  w(164),  w(165)
*      /8.02,     8.07,     8.12,     8.17,     8.22    /
  data f(161),  f(162),  f(163),  f(164),  f(165)
*      /.0040831,.0040044,.0039277,.0038529,.0037802/

  data w(166),  w(167),  w(168),  w(169),  w(170)
*      /8.27,     8.32,     8.37,     8.42,     8.47    /
  data f(166),  f(167),  f(168),  f(169),  f(170)
*      /.0037092,.0036400,.0035725,.0035067,.0034424/

  data w(171),  w(172),  w(173),  w(174),  w(175)
*      /8.52,     8.57,     8.62,     8.67,     8.72    /
  data f(171),  f(172),  f(173),  f(174),  f(175)
*      /.0033797,.0033185,.0032588,.0032006,.0031437/

  data w(176),  w(177),  w(178),  w(179),  w(180)
*      /8.77,     8.82,     8.87,     8.92,     8.97    /
  data f(176),  f(177),  f(178),  f(179),  f(180)
*      /.0030881,.0030337,.0029807,.0029289,.0028783/

  data w(181),  w(182),  w(183),  w(184),  w(185)
*      /9.02,     9.07,     9.12,     9.17,     9.22    /
  data f(181),  f(182),  f(183),  f(184),  f(185)
*      /.0028289,.0027805,.0027332,.0026369,.0026418/

  data w(186),  w(187),  w(188),  w(189),  w(190)
*      /9.27,     9.32,     9.37,     9.42,     9.47    /
  data f(186),  f(187),  f(188),  f(189),  f(190)
*      /.0025978,.0025546,.0025124,.0024711,.0024306/

  data w(191),  w(192),  w(193),  w(194),  w(195)
*      /9.52,     9.57,     9.62,     9.67,     9.72    /
  data f(191),  f(192),  f(193),  f(194),  f(195)
*      /.0023909,.0023523,.0023144,.0022774,.0022412/

  data w(196),  w(197),  w(198),  w(199),  w(200)
*      /9.77,     9.82,     9.87,     9.92,     9.97    /
  data f(196),  f(197),  f(198),  f(199),  f(200)
*      /.0022057,.0021708,.0021367,.0021033,.00207068/
```

```
      do 5 i = 2, n-1
        if(u.le.w(i)) goto 15
5     continue

      i = n-1
      goto 70

15    if(i.eq.2) goto 70

      if((u-w(i-1)).lt.(w(i)-u)) i = i-1

70    x1 = w(i-1)
      x2 = w(i)
      x3 = w(i+1)

      a1 = (u-x2)*(u-x3)/((x1-x2)*(x1-x3))
      a2 = (u-x1)*(u-x3)/((x2-x1)*(x2-x3))
      a3 = (u-x1)*(u-x2)/((x3-x1)*(x3-x2))

      fw = a1*f(i-1) + a2*f(i) +a3*f(i+1)

      return
      end
```

APPENDIX II

VALUE OF b, I, AND SHELL CORRECTION PARAMETERS

FOR THE FIRST 18 ELEMENTS

Z	Element	I(eV)	b	Shell Correction Parameters			
				V_L	H_L	V_M	H_M
1	H	19.3	1.90	0.000	----	-----	----
2	He	41.8	1.87	0.000	----	-----	----
3	Li	40.0	1.84	0.125	1.00	-----	----
4	Be	63.7	1.81	0.250	1.00	-----	----
5	B	76.0	1.78	0.375	1.00	-----	----
6	C	78.0	1.76	0.500	1.00	-----	----
7	N	81.8	1.73	0.625	1.00	-----	----
8	O	95.0	1.70	0.750	1.00	-----	----
9	F	115	1.67	0.875	1.00	-----	----
10	Ne	130	1.64	1.000	1.00	-----	----
11	Na	149	1.55	1.000	1.00	0.125	12.0
12	Mg	156	1.46	1.000	1.00	0.250	12.0
13	Al	165	1.37	1.000	1.00	0.375	12.0
14	Si	173	1.52	1.000	1.00	0.500	12.0
15	P	173	1.66	1.000	1.00	0.625	12.0
16	S	180	1.81	1.000	1.00	0.750	12.0
17	Cl	174	1.95	1.000	1.00	0.875	12.0
18	Ar	184	2.10	1.000	1.00	1.000	12.0

DATA OF L_0 FOR α OR PROTON AS A FUNCTION OF ENERGY

Target : H		Target : He		Target : Li	
E_p(MeV)	L_0	E_α(Mev)	L_0	E_p(MeV)	L_0
0.1	2.4233	1.0	2.5734	0.1	1.4468
0.2	3.1164	1.5	2.9787	0.2	2.0550
0.3	3.5218	2.0	3.2663	0.3	2.4833
0.4	3.8093	2.5	3.4892	0.4	2.8088
0.5	4.0323	3.0	3.6714	0.5	3.0643
0.6	4.2145	3.5	3.8254	0.75	3.5332
0.78	4.4766	4.0	3.9589	1.0	3.8568
1.04	4.7638	4.5	4.0763	1.5	4.3038
1.56	5.1685	5.0	4.1814	2.0	4.6153
2.07	5.4505	5.5	4.2766	2.5	4.8520
2.59	5.6738	6.0	4.3634	3.0	5.0435
3.0	5.8201	6.5	4.4432	3.5	5.2040
3.5	5.9735	7.0	4.5172	4.0	5.3421
4.0	6.1062	7.5	4.5859	4.5	5.4632
4.43	6.2077	8.0	4.6503	5.0	5.5711
4.8	6.2873	8.5	4.7107		
		9.0	4.7677		
		10.0	4.8726		
		12.0	5.0542		
		14.0	5.2075		
		16.0	5.3403		
		18.0	5.4573		
		20.0	5.5618		

DATA OF L_{ψ} FOR α OR PROTON AS A FUNCTION OF ENERGY

Target : Be		Target : B		Target : C	
E_p(MeV)	L_{ψ}	E_p(Mev)	L_{ψ}	E_p(MeV)	L_{ψ}
0.1	1.2418	0.1	1.1897	0.1	1.1491
0.2	1.7414	0.2	1.6877	0.2	1.7082
0.3	2.0931	0.3	2.0113	0.3	2.0410
0.4	2.3731	0.4	2.2608	0.4	2.2862
0.5	2.6027	0.5	2.4683	0.5	2.4850
0.75	3.0433	0.75	2.8731	0.75	2.8670
1.0	3.1613	1.0	3.1772	1.0	3.1554
1.5	3.8119	1.5	3.6154	1.5	3.5808
2.0	4.1247	2.0	3.9296	2.0	3.8886
2.5	4.3645	2.5	4.1708	2.5	4.1288
3.0	4.5584	3.0	4.3657	3.0	4.3254
3.5	4.7222	3.5	4.5294	3.5	4.4902
4.0	4.8618	4.0	4.6704	4.0	4.6315
4.5	4.9844	4.5	4.7942	4.5	4.7559
5.0	5.0935	5.0	4.9041	5.0	4.8666

DATA OF L_i FOR α OR PROTON AS A FUNCTION OF ENERGY

Target : N		Target : O		Target : F	
E_i(MeV)	L_i	E_i(Mev)	L_i	E_i(MeV)	L_i
0.1	1.0242	0.1	0.8415		
0.2	1.6375	0.2	1.4376		
0.3	1.9980	0.3	1.8165		
0.4	2.2549	0.4	2.0884		
0.5	2.4564	0.5	2.2997		
0.6	2.6251	0.6	2.4730		
0.78	2.8727	0.78	2.7252		
1.0	3.1153	1.0	2.9677		
1.2	3.2999	1.2	3.1490		
1.4	3.4567	1.4	3.3051		
1.6	3.5954	1.6	3.4427		
1.8	3.7198	1.8	3.5638		
2.0	3.8316	2.0	3.6738		
2.2	3.9330	2.2	3.7738		
2.4	4.0258	2.4	3.8660		
2.6	4.1112	2.6	3.9510		
2.8	4.1900	2.8	4.0298		
3.0	4.2638	3.0	4.1031		
3.2	4.3325	3.2	4.1719		
3.4	4.3976	3.4	4.2364		
4.43	4.6802	4.43	4.5177		
4.8	4.7651	4.8	4.6030		

DATA OF L FOR α OR PROTON AS A FUNCTION OF ENERGY

Target : Ne		:	Target : Na		:	Target : Mg	
E (MeV)	L	:	E (Mev)	L	:	E (MeV)	L
0.1	0.6921	:			:		
0.2	1.0918	:			:		
0.3	1.4312	:			:		
0.4	1.7024	:			:		
0.5	1.9223	:			:		
0.6	2.1056	:			:		
0.73	2.3046	:			:		
0.93	2.5514	:			:		
1.0	2.6254	:			:		
1.2	2.8123	:			:		
1.4	2.9708	:			:		
1.6	3.1084	:			:		
1.8	3.2303	:			:		
2.0	3.3401	:			.		
2.2	3.4398	:			:		
2.4	3.5318	:			:		
2.6	3.6158	:			:		
2.8	3.6935	:			:		
3.0	3.7664	:			:		
3.2	3.8347	:			:		
3.4	3.8939	:			.		
4.43	4.1808	:			:		
4.8	4.2661	:			.		

DATA OF L_{γ} FOR α OR PROTON AS A FUNCTION OF ENERGY

Target : Al		Target : Si		Target : P	
E_{γ}(Mev)	L_{γ}	E_{γ}(Mev)	L_{γ}	E_{γ}(MeV)	L_{γ}
0.4	0.7753	0.4	0.7957		
0.6	0.9295	0.8	1.0888		
0.7	1.0015	1.2	1.3390		
1.0	1.2145	1.6	1.5331		
1.5	1.4888	2.0	1.7060		
2.0	1.7252	2.4	1.8604		
2.5	1.9267	2.8	1.9999		
3.0	2.0999	3.2	2.1248		
3.18	2.1564	3.6	2.2377		
3.97	2.3770	4.0	2.3409		
4.77	2.5635	8.0	3.0480		
5.56	2.7209	12.0	3.4711		
6.35	2.8582	16.0	3.7727		
7.15	2.9811	20.0	4.0078		
7.94	3.0901	8.0	4.6503		
8.74	3.1902	8.5	4.7107		
9.53	3.2806	9.0	4.7677		
10.32	3.3637	10.0	4.8726		
11.12	3.4418	12.0	5.0542		
11.91	3.5136	14.0	5.2075		
12.71	3.5818	16.0	5.3403		
13.5	3.6451	18.0	5.4573		
14.3	3.7055	20.0	5.5618		

DATA OF L_{j} FOR α OR PROTON AS A FUNCTION OF ENERGY

(Continued)

Target : Al		Target : Si		Target : P	
E_{α}(Mev)	L	E_{α}(Mev)	L_{j}	E_{α}(MeV)	L_{j}
15.09	3.7622				
15.89	3.8160				
16.68	3.8681				
17.47	3.9168				
18.27	3.9639				
19.06	4.0084				
19.85	4.0511				
20.65	4.0928				
21.44	4.1325				
22.24	4.1712				

DATA OF L_{ϕ} FOR α OR PROTON AS A FUNCTION OF ENERGY

Target : S		Target : Cl		Target : Ar	
E_{p}(Mev)	L_{ϕ}	E_{p}(Mev)	L_{ϕ}	E_{p}(MeV)	L_{ϕ}
0.1	0.8460			0.1	0.8803
0.2	1.1490			0.2	1.1928
0.3	1.3759			0.3	1.4233
0.4	1.5728			0.4	1.6069
0.5	1.7292			0.5	1.7657
0.75	2.0544			0.75	2.0762
1.0	2.3145			1.0	2.3214
1.5	2.7080			1.5	2.6980
2.0	3.0001			2.0	2.9821
2.5	3.2305			2.5	3.2088
3.0	3.4200			3.0	3.3964
3.5	3.5809			3.5	3.5561
4.0	3.7206			4.0	3.6951
4.5	3.8438			4.5	3.8179
5.0	3.9542			5.0	3.9280

APPENDIX III

PROJECTILE'S ENERGY-VELOCITY CONVERSION FORMULA, TABLES AND CHARTS

Since many of the experimental data of stopping power are given as a function of the energy of the projectile, and since the values of stopping power in the theories of J. C. Ashley, R. H. Ritchie and W. Brandt [9,10,11,12], of S. H. Morgan and C. C. Sung [13], and of J. D. Jackson and R. L. McCarthy [14] are given as a function of the velocity of the projectile it is necessary to have an energy-velocity conversion table or chart to show the association between calculation and experimental data.

The tables and charts here are made according to the following formula:

$$E_k = \frac{m_0 c^2}{(1 - \beta^2)^{1/2}} - m_0 c^2 ,$$

where m_0 = the rest mass of projectile

c = the speed of light

β = v/c = velocity of projectile / velocity of light

E_k = kinetic energy of projectile

Following are the tables and charts. The computer program for this calculation is listed in Appendix I.

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.001	0.000469	0.751651E-16	0.299792E+06
0.002	0.001877	0.300661E-15	0.599585E+06
0.003	0.004222	0.676490E-15	0.899377E+06
0.004	0.007506	0.120266E-14	0.119917E+07
0.005	0.011729	0.187916E-14	0.149896E+07
0.006	0.016889	0.270602E-14	0.179875E+07
0.007	0.022989	0.368322E-14	0.209855E+07
0.008	0.030026	0.481080E-14	0.239834E+07
0.009	0.038003	0.608874E-14	0.269813E+07
0.010	0.046917	0.751707E-14	0.299792E+07
0.011	0.056771	0.909580E-14	0.329772E+07
0.012	0.067563	0.108249E-13	0.359751E+07
0.013	0.079295	0.127045E-13	0.389730E+07
0.014	0.091965	0.147345E-13	0.419709E+07
0.015	0.105574	0.169150E-13	0.449689E+07
0.016	0.120123	0.192460E-13	0.479668E+07
0.017	0.135611	0.217274E-13	0.509647E+07
0.018	0.152038	0.243594E-13	0.539626E+07
0.019	0.169405	0.271419E-13	0.569606E+07
0.020	0.187712	0.300750E-13	0.599585E+07
0.021	0.206959	0.331588E-13	0.629564E+07
0.022	0.227146	0.363931E-13	0.659543E+07
0.023	0.248273	0.397781E-13	0.689523E+07
0.024	0.270341	0.433138E-13	0.719502E+07
0.025	0.293350	0.470002E-13	0.749481E+07
0.026	0.317299	0.508374E-13	0.779460E+07
0.027	0.342190	0.548253E-13	0.809440E+07
0.028	0.368022	0.589641E-13	0.839419E+07
0.029	0.394796	0.632537E-13	0.869398E+07
0.030	0.422511	0.676943E-13	0.899377E+07
0.031	0.451169	0.722857E-13	0.929357E+07
0.032	0.480768	0.770282E-13	0.959336E+07
0.033	0.511311	0.819217E-13	0.989315E+07
0.034	0.542796	0.869662E-13	0.101929E+08
0.035	0.575225	0.921619E-13	0.104927E+08
0.036	0.608597	0.975087E-13	0.107925E+08
0.037	0.642913	0.103007E-12	0.110923E+08
0.038	0.678172	0.108656E-12	0.113921E+08
0.039	0.714377	0.114457E-12	0.116919E+08
0.040	0.751526	0.120409E-12	0.119917E+08
0.041	0.789620	0.126512E-12	0.122915E+08
0.042	0.828659	0.132767E-12	0.125913E+08
0.043	0.868644	0.139173E-12	0.128911E+08
0.044	0.909576	0.145731E-12	0.131909E+08
0.045	0.951453	0.152441E-12	0.134907E+08
0.046	0.994278	0.159302E-12	0.137905E+08
0.047	1.038050	0.166315E-12	0.140902E+08
0.048	1.082770	0.173480E-12	0.143900E+08
0.049	1.128437	0.180797E-12	0.146898E+08
0.050	1.175053	0.188266E-12	0.149896E+08

ENERGY-VELOCITY CONVERSION FOR PROTON
(Continued)

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.051	1.222618	0.195887E-12	0.152894E+08
0.052	1.271133	0.203659E-12	0.155892E+08
0.053	1.320597	0.211585E-12	0.158890E+08
0.054	1.371011	0.219662E-12	0.161888E+08
0.055	1.422376	0.227892E-12	0.164886E+08
0.056	1.474692	0.236274E-12	0.167884E+08
0.057	1.527960	0.244808E-12	0.170882E+08
0.058	1.582179	0.253495E-12	0.173880E+08
0.059	1.637352	0.262335E-12	0.176878E+08
0.060	1.693477	0.271327E-12	0.179875E+08
0.061	1.750556	0.280472E-12	0.182873E+08
0.062	1.808589	0.289770E-12	0.185871E+08
0.063	1.867577	0.299221E-12	0.188869E+08
0.064	1.927520	0.308825E-12	0.191867E+08
0.065	1.988419	0.318582E-12	0.194865E+08
0.066	2.050274	0.328493E-12	0.197863E+08
0.067	2.113086	0.338556E-12	0.200861E+08
0.068	2.176855	0.348773E-12	0.203859E+08
0.069	2.241582	0.359144E-12	0.206857E+08
0.070	2.307268	0.369668E-12	0.209855E+08
0.071	2.373913	0.380346E-12	0.212853E+08
0.072	2.441517	0.391177E-12	0.215851E+08
0.073	2.510083	0.402163E-12	0.218849E+08
0.074	2.579609	0.413302E-12	0.221846E+08
0.075	2.650097	0.424596E-12	0.224844E+08
0.076	2.721547	0.436043E-12	0.227842E+08
0.077	2.793960	0.447645E-12	0.230840E+08
0.078	2.867337	0.459402E-12	0.233838E+08
0.079	2.941678	0.471313E-12	0.236836E+08
0.080	3.016984	0.483378E-12	0.239834E+08
0.081	3.093256	0.495598E-12	0.242832E+08
0.082	3.170494	0.507973E-12	0.245830E+08
0.083	3.248699	0.520503E-12	0.248828E+08
0.084	3.327872	0.533188E-12	0.251826E+08
0.085	3.408014	0.546028E-12	0.254824E+08
0.086	3.489125	0.559024E-12	0.257822E+08
0.087	3.571205	0.572175E-12	0.260819E+08
0.088	3.654256	0.585481E-12	0.263817E+08
0.089	3.738280	0.598943E-12	0.266815E+08
0.090	3.823275	0.612561E-12	0.269813E+08
0.091	3.909243	0.626335E-12	0.272811E+08
0.092	3.996185	0.640264E-12	0.275809E+08
0.093	4.084102	0.654350E-12	0.278807E+08
0.094	4.172994	0.668593E-12	0.281805E+08
0.095	4.262863	0.682991E-12	0.284803E+08
0.096	4.353709	0.697547E-12	0.287801E+08
0.097	4.445532	0.712258E-12	0.290799E+08
0.098	4.538334	0.727127E-12	0.293797E+08
0.099	4.632117	0.742153E-12	0.296795E+08
0.100	4.726880	0.757336E-12	0.299792E+08

ENERGY-VELOCITY CONVERSION FOR PROTON
(Continued)

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.101	4.822624	0.772676E-12	0.302790E+08
0.102	4.919350	0.788173E-12	0.305788E+08
0.103	5.017059	0.803828E-12	0.308786E+08
0.104	5.115753	0.819640E-12	0.311784E+08
0.105	5.215431	0.835611E-12	0.314782E+08
0.106	5.316096	0.851739E-12	0.317780E+08
0.107	5.417747	0.868026E-12	0.320778E+08
0.108	5.520387	0.884470E-12	0.323776E+08
0.109	5.624014	0.901073E-12	0.326774E+08
0.110	5.728632	0.917835E-12	0.329772E+08
0.111	5.834240	0.934756E-12	0.332770E+08
0.112	5.940840	0.951835E-12	0.335768E+08
0.113	6.048432	0.969073E-12	0.338765E+08
0.114	6.157019	0.986471E-12	0.341763E+08
0.115	6.266600	0.100403E-11	0.344761E+08
0.116	6.377176	0.102174E-11	0.347759E+08
0.117	6.488750	0.103962E-11	0.350757E+08
0.118	6.601321	0.105766E-11	0.353755E+08
0.119	6.714891	0.107585E-11	0.356753E+08
0.120	6.829461	0.109421E-11	0.359751E+08
0.121	6.945031	0.111273E-11	0.362749E+08
0.122	7.061604	0.113140E-11	0.365747E+08
0.123	7.179181	0.115024E-11	0.368745E+08
0.124	7.297760	0.116924E-11	0.371743E+08
0.125	7.417346	0.118840E-11	0.374741E+08
0.126	7.537938	0.120772E-11	0.377739E+08
0.127	7.659538	0.122720E-11	0.380736E+08
0.128	7.782146	0.124685E-11	0.383734E+08
0.129	7.905763	0.126665E-11	0.386732E+08
0.130	8.030392	0.128662E-11	0.389730E+08
0.131	8.156034	0.130675E-11	0.392728E+08
0.132	8.282689	0.132704E-11	0.395726E+08
0.133	8.410358	0.134750E-11	0.398724E+08
0.134	8.539044	0.136812E-11	0.401722E+08
0.135	8.668746	0.138890E-11	0.404720E+08
0.136	8.799467	0.140984E-11	0.407718E+08
0.137	8.931206	0.143095E-11	0.410716E+08
0.138	9.063967	0.145222E-11	0.413714E+08
0.139	9.197749	0.147365E-11	0.416712E+08
0.140	9.332556	0.149525E-11	0.419709E+08
0.141	9.468386	0.151701E-11	0.422707E+08
0.142	9.605243	0.153894E-11	0.425705E+08
0.143	9.743126	0.156103E-11	0.428703E+08
0.144	9.882036	0.158329E-11	0.431701E+08
0.145	10.021980	0.160571E-11	0.434699E+08
0.146	10.162950	0.162830E-11	0.437697E+08
0.147	10.304960	0.165105E-11	0.440695E+08
0.148	10.448000	0.167397E-11	0.443693E+08
0.149	10.592070	0.169705E-11	0.446691E+08
0.150	10.737180	0.172030E-11	0.449689E+08

ENERGY-VELOCITY CONVERSION FOR PROTON
(Continued)

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.151	10.883330	0.174371E-11	0.452687E+08
0.152	11.030510	0.176730E-11	0.455685E+08
0.153	11.178740	0.179105E-11	0.458682E+08
0.154	11.328010	0.181496E-11	0.461680E+08
0.155	11.478330	0.183905E-11	0.464678E+08
0.156	11.629690	0.186330E-11	0.467676E+08
0.157	11.782090	0.188771E-11	0.470674E+08
0.158	11.935550	0.191230E-11	0.473672E+08
0.159	12.090050	0.193705E-11	0.476670E+08
0.160	12.245600	0.196198E-11	0.479668E+08
0.161	12.402210	0.198707E-11	0.482666E+08
0.162	12.559870	0.201233E-11	0.485664E+08
0.163	12.718590	0.203776E-11	0.488662E+08
0.164	12.878360	0.206336E-11	0.491660E+08
0.165	13.039190	0.208912E-11	0.494658E+08
0.166	13.201080	0.211506E-11	0.497655E+08
0.167	13.364030	0.214117E-11	0.500653E+08
0.168	13.528050	0.216745E-11	0.503651E+08
0.169	13.693130	0.219390E-11	0.506649E+08
0.170	13.859270	0.222052E-11	0.509647E+08
0.171	14.026490	0.224731E-11	0.512645E+08
0.172	14.194780	0.227427E-11	0.515643E+08
0.173	14.364130	0.230141E-11	0.518641E+08
0.174	14.534560	0.232871E-11	0.521639E+08
0.175	14.706060	0.235619E-11	0.524637E+08
0.176	14.878640	0.238384E-11	0.527635E+08
0.177	15.052300	0.241166E-11	0.530633E+08
0.178	15.227040	0.243966E-11	0.533631E+08
0.179	15.402860	0.246783E-11	0.536629E+08
0.180	15.579760	0.249617E-11	0.539626E+08
0.181	15.757740	0.252469E-11	0.542624E+08
0.182	15.936820	0.255338E-11	0.545622E+08
0.183	16.116980	0.258224E-11	0.548620E+08
0.184	16.298230	0.261128E-11	0.551618E+08
0.185	16.480570	0.264050E-11	0.554616E+08
0.186	16.664010	0.266989E-11	0.557614E+08
0.187	16.848550	0.269946E-11	0.560612E+08
0.188	17.034170	0.272920E-11	0.563610E+08
0.189	17.220900	0.275911E-11	0.566608E+08
0.190	17.408730	0.278921E-11	0.569606E+08
0.191	17.597670	0.281948E-11	0.572604E+08
0.192	17.787700	0.284993E-11	0.575602E+08
0.193	17.978850	0.288055E-11	0.578599E+08
0.194	18.171100	0.291135E-11	0.581597E+08
0.195	18.364460	0.294233E-11	0.584595E+08
0.196	18.558940	0.297349E-11	0.587593E+08
0.197	18.754530	0.300483E-11	0.590591E+08
0.198	18.951240	0.303635E-11	0.593589E+08
0.199	19.149060	0.306804E-11	0.596587E+08
0.200	19.348010	0.309992E-11	0.599585E+08

ENERGY-VELOCITY CONVERSION FOR PROTON
(Continued)

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.201	19.548070	0.313197E-11	0.602583E+08
0.202	19.749270	0.316421E-11	0.605581E+08
0.203	19.951580	0.319662E-11	0.608579E+08
0.204	20.155030	0.322922E-11	0.611577E+08
0.205	20.359610	0.326199E-11	0.614575E+08
0.206	20.565320	0.329495E-11	0.617572E+08
0.207	20.772160	0.332809E-11	0.620570E+08
0.208	20.980140	0.336142E-11	0.623568E+08
0.209	21.189260	0.339492E-11	0.626566E+08
0.210	21.399510	0.342861E-11	0.629564E+08
0.211	21.610920	0.346248E-11	0.632562E+08
0.212	21.823460	0.349653E-11	0.635560E+08
0.213	22.037160	0.353077E-11	0.638558E+08
0.214	22.252000	0.356519E-11	0.641556E+08
0.215	22.468000	0.359980E-11	0.644554E+08
0.216	22.685150	0.363459E-11	0.647552E+08
0.217	22.903450	0.366957E-11	0.650550E+08
0.218	23.122910	0.370473E-11	0.653548E+08
0.219	23.343540	0.374008E-11	0.656545E+08
0.220	23.565320	0.377561E-11	0.659543E+08
0.221	23.788280	0.381133E-11	0.662541E+08
0.222	24.012400	0.384724E-11	0.665539E+08
0.223	24.237680	0.388334E-11	0.668537E+08
0.224	24.464150	0.391962E-11	0.671535E+08
0.225	24.691780	0.395609E-11	0.674533E+08
0.226	24.920590	0.399275E-11	0.677531E+08
0.227	25.150580	0.402960E-11	0.680529E+08
0.228	25.381750	0.406664E-11	0.683527E+08
0.229	25.614110	0.410386E-11	0.686525E+08
0.230	25.847650	0.414128E-11	0.689523E+08
0.231	26.082380	0.417889E-11	0.692521E+08
0.232	26.318290	0.421669E-11	0.695518E+08
0.233	26.555410	0.425468E-11	0.698516E+08
0.234	26.793720	0.429286E-11	0.701514E+08
0.235	27.033230	0.433123E-11	0.704512E+08
0.236	27.273940	0.436980E-11	0.707510E+08
0.237	27.515850	0.440856E-11	0.710508E+08
0.238	27.758970	0.444751E-11	0.713506E+08
0.239	28.003300	0.448666E-11	0.716504E+08
0.240	28.248830	0.452600E-11	0.719502E+08
0.241	28.495590	0.456553E-11	0.722500E+08
0.242	28.743560	0.460526E-11	0.725498E+08
0.243	28.992740	0.464519E-11	0.728496E+08
0.244	29.243150	0.468531E-11	0.731494E+08
0.245	29.494790	0.472562E-11	0.734492E+08
0.246	29.747650	0.476614E-11	0.737489E+08
0.247	30.001730	0.480685E-11	0.740487E+08
0.248	30.257050	0.484775E-11	0.743485E+08
0.249	30.513610	0.488886E-11	0.746483E+08
0.250	30.771400	0.493016E-11	0.749481E+08

ENERGY-VELOCITY CONVERSION FOR PROTON
(Continued)

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.251	31.030440	0.497166E-11	0.752479E+08
0.252	31.290720	0.501337E-11	0.755477E+08
0.253	31.552240	0.505527E-11	0.758475E+08
0.254	31.815010	0.509737E-11	0.761473E+08
0.255	32.079030	0.513967E-11	0.764471E+08
0.256	32.344320	0.518217E-11	0.767469E+08
0.257	32.610850	0.522488E-11	0.770467E+08
0.258	32.878640	0.526778E-11	0.773464E+08
0.259	33.147710	0.531089E-11	0.776462E+08
0.260	33.418030	0.535420E-11	0.779460E+08
0.261	33.689620	0.539771E-11	0.782458E+08
0.262	33.962480	0.544143E-11	0.785456E+08
0.263	34.236630	0.548536E-11	0.788454E+08
0.264	34.512040	0.552948E-11	0.791452E+08
0.265	34.788730	0.557381E-11	0.794450E+08
0.266	35.066720	0.561835E-11	0.797448E+08
0.267	35.345990	0.566310E-11	0.800446E+08
0.268	35.626550	0.570805E-11	0.803444E+08
0.269	35.908400	0.575320E-11	0.806442E+08
0.270	36.191550	0.579857E-11	0.809440E+08
0.271	36.475990	0.584414E-11	0.812438E+08
0.272	36.761750	0.588993E-11	0.815436E+08
0.273	37.048790	0.593592E-11	0.818433E+08
0.274	37.337150	0.598212E-11	0.821431E+08
0.275	37.626830	0.602853E-11	0.824429E+08
0.276	37.917820	0.607515E-11	0.827427E+08
0.277	38.210130	0.612199E-11	0.830425E+08
0.278	38.503750	0.616903E-11	0.833423E+08
0.279	38.798710	0.621629E-11	0.836421E+08
0.280	39.094990	0.626376E-11	0.839419E+08
0.281	39.392590	0.631144E-11	0.842417E+08
0.282	39.691540	0.635934E-11	0.845415E+08
0.283	39.991830	0.640745E-11	0.848413E+08
0.284	40.293450	0.645577E-11	0.851411E+08
0.285	40.596420	0.650431E-11	0.854408E+08
0.286	40.900740	0.655307E-11	0.857406E+08
0.287	41.206410	0.660205E-11	0.860404E+08
0.288	41.513430	0.665124E-11	0.863402E+08
0.289	41.821820	0.670065E-11	0.866400E+08
0.290	42.131550	0.675027E-11	0.869398E+08
0.291	42.442670	0.680012E-11	0.872396E+08
0.292	42.755140	0.685018E-11	0.875394E+08
0.293	43.069000	0.690047E-11	0.878392E+08
0.294	43.384220	0.695097E-11	0.881390E+08
0.295	43.700820	0.700170E-11	0.884388E+08
0.296	44.018820	0.705265E-11	0.887386E+08
0.297	44.338190	0.710382E-11	0.890384E+08
0.298	44.658960	0.715521E-11	0.893382E+08
0.299	44.981120	0.720683E-11	0.896379E+08
0.300	45.304680	0.725867E-11	0.899377E+08

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.001	0.001864	0.298601E-15	0.299792E+06
0.002	0.007455	0.119441E-14	0.599585E+06
0.003	0.016773	0.268742E-14	0.899377E+06
0.004	0.029820	0.477767E-14	0.119917E+07
0.005	0.046593	0.746516E-14	0.149896E+07
0.006	0.067095	0.107499E-13	0.179875E+07
0.007	0.091325	0.146320E-13	0.209855E+07
0.008	0.119283	0.191114E-13	0.239834E+07
0.009	0.150969	0.241881E-13	0.269813E+07
0.010	0.186384	0.298623E-13	0.299792E+07
0.011	0.225529	0.361340E-13	0.329772E+07
0.012	0.268402	0.430031E-13	0.359751E+07
0.013	0.315006	0.504699E-13	0.389730E+07
0.014	0.365340	0.585343E-13	0.419709E+07
0.015	0.419404	0.671965E-13	0.449689E+07
0.016	0.477200	0.764565E-13	0.479668E+07
0.017	0.538727	0.863143E-13	0.509647E+07
0.018	0.603987	0.967701E-13	0.539626E+07
0.019	0.672979	0.107824E-12	0.569606E+07
0.020	0.745705	0.119476E-12	0.599585E+07
0.021	0.822165	0.131726E-12	0.629564E+07
0.022	0.902360	0.144575E-12	0.659543E+07
0.023	0.986291	0.158022E-12	0.689523E+07
0.024	1.073958	0.172068E-12	0.719502E+07
0.025	1.165361	0.186713E-12	0.749481E+07
0.026	1.260503	0.201956E-12	0.779460E+07
0.027	1.359384	0.217799E-12	0.809440E+07
0.028	1.462004	0.234241E-12	0.839419E+07
0.029	1.568364	0.251282E-12	0.869398E+07
0.030	1.678467	0.268922E-12	0.899377E+07
0.031	1.792312	0.287162E-12	0.929357E+07
0.032	1.909900	0.306002E-12	0.959336E+07
0.033	2.031233	0.325442E-12	0.989315E+07
0.034	2.156312	0.345482E-12	0.101929E+08
0.035	2.285137	0.366122E-12	0.104927E+08
0.036	2.417711	0.387363E-12	0.107925E+08
0.037	2.554034	0.409205E-12	0.110923E+08
0.038	2.694107	0.431647E-12	0.113921E+08
0.039	2.837932	0.454690E-12	0.116919E+08
0.040	2.985510	0.478335E-12	0.119917E+08
0.041	3.136842	0.502581E-12	0.122915E+08
0.042	3.291930	0.527429E-12	0.125913E+08
0.043	3.450775	0.552880E-12	0.128911E+08
0.044	3.613379	0.578932E-12	0.131909E+08
0.045	3.779743	0.605586E-12	0.134907E+08
0.046	3.949867	0.632843E-12	0.137905E+08
0.047	4.123755	0.660704E-12	0.140902E+08
0.048	4.301409	0.689167E-12	0.143900E+08
0.049	4.482828	0.718234E-12	0.146898E+08
0.050	4.668015	0.747904E-12	0.149896E+08

ENERGY-VELOCITY CONVERSION FOR ALPHA PARTICLES
(Continued)

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.051	4.856971	0.778179E-12	0.152894E+08
0.052	5.049699	0.809057E-12	0.155892E+08
0.053	5.246200	0.840540E-12	0.158890E+08
0.054	5.446476	0.872628E-12	0.161888E+08
0.055	5.650528	0.905321E-12	0.164886E+08
0.056	5.858359	0.938620E-12	0.167884E+08
0.057	6.069970	0.972524E-12	0.170882E+08
0.058	6.285363	0.100703E-11	0.173880E+08
0.059	6.504541	0.104215E-11	0.176878E+08
0.060	6.727504	0.107787E-11	0.179875E+08
0.061	6.954257	0.111420E-11	0.182873E+08
0.062	7.184799	0.115114E-11	0.185871E+08
0.063	7.419134	0.118869E-11	0.188869E+08
0.064	7.657264	0.122684E-11	0.191867E+08
0.065	7.899189	0.126560E-11	0.194865E+08
0.066	8.144915	0.130497E-11	0.197863E+08
0.067	8.394441	0.134495E-11	0.200861E+08
0.068	8.647771	0.138554E-11	0.203859E+08
0.069	8.904905	0.142673E-11	0.206857E+08
0.070	9.165849	0.146854E-11	0.209855E+08
0.071	9.430603	0.151096E-11	0.212853E+08
0.072	9.699168	0.155399E-11	0.215851E+08
0.073	9.971551	0.159763E-11	0.218849E+08
0.074	10.247750	0.164188E-11	0.221846E+08
0.075	10.527770	0.168675E-11	0.224844E+08
0.076	10.811610	0.173222E-11	0.227842E+08
0.077	11.099280	0.177832E-11	0.230840E+08
0.078	11.390780	0.182502E-11	0.233838E+08
0.079	11.686110	0.187234E-11	0.236836E+08
0.080	11.985270	0.192027E-11	0.239834E+08
0.081	12.288260	0.196881E-11	0.242832E+08
0.082	12.595100	0.201797E-11	0.245830E+08
0.083	12.905780	0.206775E-11	0.248828E+08
0.084	13.220300	0.211814E-11	0.251826E+08
0.085	13.538670	0.216915E-11	0.254824E+08
0.086	13.860890	0.222078E-11	0.257822E+08
0.087	14.186960	0.227302E-11	0.260819E+08
0.088	14.516890	0.232588E-11	0.263817E+08
0.089	14.850680	0.237936E-11	0.266815E+08
0.090	15.188340	0.243346E-11	0.269813E+08
0.091	15.529850	0.248818E-11	0.272811E+08
0.092	15.875240	0.254351E-11	0.275809E+08
0.093	16.224500	0.259947E-11	0.278807E+08
0.094	16.577630	0.265605E-11	0.281805E+08
0.095	16.934640	0.271325E-11	0.284803E+08
0.096	17.295540	0.277107E-11	0.287801E+08
0.097	17.660320	0.282952E-11	0.290799E+08
0.098	18.028980	0.288858E-11	0.293797E+08
0.099	18.401540	0.294827E-11	0.296795E+08
0.100	18.777990	0.300859E-11	0.299792E+08

ENERGY-VELOCITY CONVERSION FOR ALPHA PARTICLES
(Continued)

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.101	19.158350	0.306953E-11	0.302790E+08
0.102	19.542600	0.313109E-11	0.305788E+08
0.103	19.930760	0.319329E-11	0.308786E+08
0.104	20.322830	0.325610E-11	0.311784E+08
0.105	20.718810	0.331955E-11	0.314782E+08
0.106	21.118720	0.338362E-11	0.317780E+08
0.107	21.522540	0.344832E-11	0.320778E+08
0.108	21.930280	0.351365E-11	0.323776E+08
0.109	22.341950	0.357960E-11	0.326774E+08
0.110	22.757560	0.364619E-11	0.329772E+08
0.111	23.177100	0.371341E-11	0.332770E+08
0.112	23.600570	0.378126E-11	0.335768E+08
0.113	24.027990	0.384974E-11	0.338765E+08
0.114	24.459360	0.391885E-11	0.341763E+08
0.115	24.894690	0.398860E-11	0.344761E+08
0.116	25.333960	0.405898E-11	0.347759E+08
0.117	25.777200	0.412999E-11	0.350757E+08
0.118	26.224400	0.420164E-11	0.353755E+08
0.119	26.675570	0.427393E-11	0.356753E+08
0.120	27.130700	0.434685E-11	0.359751E+08
0.121	27.589820	0.442041E-11	0.362749E+08
0.122	28.052920	0.449461E-11	0.365747E+08
0.123	28.520000	0.456944E-11	0.368745E+08
0.124	28.991070	0.464492E-11	0.371743E+08
0.125	29.466140	0.472103E-11	0.374741E+08
0.126	29.945200	0.479779E-11	0.377739E+08
0.127	30.428270	0.487518E-11	0.380736E+08
0.128	30.915340	0.495322E-11	0.383734E+08
0.129	31.406420	0.503190E-11	0.386732E+08
0.130	31.901520	0.511123E-11	0.389730E+08
0.131	32.400650	0.519120E-11	0.392728E+08
0.132	32.903800	0.527181E-11	0.395726E+08
0.133	33.410980	0.535307E-11	0.398724E+08
0.134	33.922190	0.543498E-11	0.401722E+08
0.135	34.437450	0.551753E-11	0.404720E+08
0.136	34.956750	0.560073E-11	0.407718E+08
0.137	35.480090	0.568458E-11	0.410716E+08
0.138	36.007500	0.576908E-11	0.413714E+08
0.139	36.538960	0.585423E-11	0.416712E+08
0.140	37.074500	0.594004E-11	0.419709E+08
0.141	37.614100	0.602649E-11	0.422707E+08
0.142	38.157770	0.611360E-11	0.425705E+08
0.143	38.705530	0.620136E-11	0.428703E+08
0.144	39.257360	0.628977E-11	0.431701E+08
0.145	39.813290	0.637884E-11	0.434699E+08
0.146	40.373330	0.646857E-11	0.437697E+08
0.147	40.937450	0.655895E-11	0.440695E+08
0.148	41.505690	0.665000E-11	0.443693E+08
0.149	42.078040	0.674170E-11	0.446691E+08
0.150	42.654510	0.683406E-11	0.449689E+08

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.151	43.235090	0.692708E-11	0.452687E+08
0.152	43.819810	0.702076E-11	0.455685E+08
0.153	44.408660	0.711511E-11	0.458682E+08
0.154	45.001650	0.721012E-11	0.461680E+08
0.155	45.598790	0.730579E-11	0.464678E+08
0.156	46.200080	0.740213E-11	0.467676E+08
0.157	46.805530	0.749913E-11	0.470674E+08
0.158	47.415140	0.759680E-11	0.473672E+08
0.159	48.028910	0.769514E-11	0.476670E+08
0.160	48.646860	0.779415E-11	0.479668E+08
0.161	49.269000	0.789383E-11	0.482666E+08
0.162	49.895320	0.799417E-11	0.485664E+08
0.163	50.525830	0.809519E-11	0.488662E+08
0.164	51.160550	0.819689E-11	0.491660E+08
0.165	51.799460	0.829925E-11	0.494658E+08
0.166	52.442580	0.840229E-11	0.497655E+08
0.167	53.089930	0.850601E-11	0.500653E+08
0.168	53.741500	0.861040E-11	0.503651E+08
0.169	54.397300	0.871548E-11	0.506649E+08
0.170	55.057330	0.882123E-11	0.509647E+08
0.171	55.721610	0.892766E-11	0.512645E+08
0.172	56.390140	0.903477E-11	0.515643E+08
0.173	57.062920	0.914256E-11	0.518641E+08
0.174	57.739960	0.925103E-11	0.521639E+08
0.175	58.421280	0.936019E-11	0.524637E+08
0.176	59.106870	0.947004E-11	0.527635E+08
0.177	59.796750	0.958057E-11	0.530633E+08
0.178	60.490910	0.969179E-11	0.533631E+08
0.179	61.189370	0.980369E-11	0.536629E+08
0.180	61.892130	0.991629E-11	0.539626E+08
0.181	62.599190	0.100296E-10	0.542624E+08
0.182	63.310570	0.101436E-10	0.545622E+08
0.183	64.026280	0.102582E-10	0.548620E+08
0.184	64.746320	0.103736E-10	0.551618E+08
0.185	65.470700	0.104896E-10	0.554616E+08
0.186	66.199420	0.106064E-10	0.557614E+08
0.187	66.932500	0.107239E-10	0.560612E+08
0.188	67.669930	0.108420E-10	0.563610E+08
0.189	68.411730	0.109609E-10	0.566608E+08
0.190	69.157910	0.110804E-10	0.569606E+08
0.191	69.908460	0.112007E-10	0.572604E+08
0.192	70.663410	0.113216E-10	0.575602E+08
0.193	71.422750	0.114433E-10	0.578599E+08
0.194	72.186490	0.115656E-10	0.581597E+08
0.195	72.954640	0.116887E-10	0.584595E+08
0.196	73.727220	0.118125E-10	0.587593E+08
0.197	74.504220	0.119370E-10	0.590591E+08
0.198	75.285660	0.120622E-10	0.593589E+08
0.199	76.071540	0.121881E-10	0.596587E+08
0.200	76.861870	0.123147E-10	0.599585E+08

(Continued)

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.201	77.656650	0.124421E-10	0.602583E+08
0.202	78.455910	0.125701E-10	0.605581E+08
0.203	79.259630	0.126989E-10	0.608579E+08
0.204	80.067840	0.128284E-10	0.611577E+08
0.205	80.880540	0.129586E-10	0.614575E+08
0.206	81.697740	0.130895E-10	0.617572E+08
0.207	82.519450	0.132212E-10	0.620570E+08
0.208	83.345660	0.133536E-10	0.623568E+08
0.209	84.176410	0.134867E-10	0.626566E+08
0.210	85.011670	0.136205E-10	0.629564E+08
0.211	85.851490	0.137550E-10	0.632562E+08
0.212	86.695860	0.138903E-10	0.635560E+08
0.213	87.544780	0.140263E-10	0.638558E+08
0.214	88.398270	0.141631E-10	0.641556E+08
0.215	89.256340	0.143006E-10	0.644554E+08
0.216	90.118990	0.144388E-10	0.647552E+08
0.217	90.986210	0.145777E-10	0.650550E+08
0.218	91.858060	0.147174E-10	0.653548E+08
0.219	92.734500	0.148578E-10	0.656545E+08
0.220	93.615570	0.149990E-10	0.659543E+08
0.221	94.501270	0.151409E-10	0.662541E+08
0.222	95.391610	0.152835E-10	0.665539E+08
0.223	96.286590	0.154269E-10	0.668537E+08
0.224	97.186230	0.155711E-10	0.671535E+08
0.225	98.090520	0.157160E-10	0.674533E+08
0.226	98.999490	0.158616E-10	0.677531E+08
0.227	99.913150	0.160080E-10	0.680529E+08
0.228	100.831500	0.161551E-10	0.683527E+08
0.229	101.754600	0.163030E-10	0.686525E+08
0.230	102.682300	0.164517E-10	0.689523E+08
0.231	103.614800	0.166011E-10	0.692521E+08
0.232	104.552000	0.167512E-10	0.695518E+08
0.233	105.494000	0.169021E-10	0.698516E+08
0.234	106.440700	0.170538E-10	0.701514E+08
0.235	107.392200	0.172063E-10	0.704512E+08
0.236	108.348400	0.173595E-10	0.707510E+08
0.237	109.309400	0.175134E-10	0.710508E+08
0.238	110.275300	0.176682E-10	0.713506E+08
0.239	111.245800	0.178237E-10	0.716504E+08
0.240	112.221300	0.179800E-10	0.719502E+08
0.241	113.201500	0.181370E-10	0.722500E+08
0.242	114.186600	0.182949E-10	0.725498E+08
0.243	115.176500	0.184535E-10	0.728496E+08
0.244	116.171300	0.186128E-10	0.731494E+08
0.245	117.170900	0.187730E-10	0.734492E+08
0.246	118.175500	0.189339E-10	0.737489E+08
0.247	119.184800	0.190957E-10	0.740487E+08
0.248	120.199100	0.192582E-10	0.743485E+08
0.249	121.218300	0.194215E-10	0.746483E+08
0.250	122.242400	0.195856E-10	0.749481E+08

(Continued)

Beta (v/c)	Energy (MeV)	Energy (joule)	Velocity (m/s)
0.251	123.271500	0.197504E-10	0.752479E+08
0.252	124.305500	0.199161E-10	0.755477E+08
0.253	125.344400	0.200825E-10	0.758475E+08
0.254	126.388300	0.202498E-10	0.761473E+08
0.255	127.437100	0.204178E-10	0.764471E+08
0.256	128.491000	0.205867E-10	0.767469E+08
0.257	129.549800	0.207563E-10	0.770467E+08
0.258	130.613600	0.209268E-10	0.773464E+08
0.259	131.682500	0.210980E-10	0.776462E+08
0.260	132.756400	0.212701E-10	0.779460E+08
0.261	133.835300	0.214430E-10	0.782458E+08
0.262	134.919300	0.216166E-10	0.785456E+08
0.263	136.008400	0.217911E-10	0.788454E+08
0.264	137.102500	0.219664E-10	0.791452E+08
0.265	138.201700	0.221425E-10	0.794450E+08
0.266	139.306000	0.223195E-10	0.797448E+08
0.267	140.415400	0.224972E-10	0.800446E+08
0.268	141.530000	0.226758E-10	0.803444E+08
0.269	142.649600	0.228552E-10	0.806442E+08
0.270	143.774500	0.230354E-10	0.809440E+08
0.271	144.904500	0.232164E-10	0.812438E+08
0.272	146.039700	0.233983E-10	0.815436E+08
0.273	147.180000	0.235810E-10	0.818433E+08
0.274	148.325500	0.237646E-10	0.821431E+08
0.275	149.476300	0.239489E-10	0.824429E+08
0.276	150.632300	0.241341E-10	0.827427E+08
0.277	151.793500	0.243202E-10	0.830425E+08
0.278	152.959900	0.245071E-10	0.833423E+08
0.279	154.131700	0.246948E-10	0.836421E+08
0.280	155.308700	0.248834E-10	0.839419E+08
0.281	156.491000	0.250728E-10	0.842417E+08
0.282	157.678600	0.252631E-10	0.845415E+08
0.283	158.871500	0.254542E-10	0.848413E+08
0.284	160.069700	0.256462E-10	0.851411E+08
0.285	161.273300	0.258390E-10	0.854408E+08
0.286	162.482200	0.260327E-10	0.857406E+08
0.287	163.696500	0.262273E-10	0.860404E+08
0.288	164.916200	0.264227E-10	0.863402E+08
0.289	166.141300	0.266190E-10	0.866400E+08
0.290	167.371700	0.268161E-10	0.869398E+08
0.291	168.607700	0.270141E-10	0.872396E+08
0.292	169.849000	0.272130E-10	0.875394E+08
0.293	171.095800	0.274128E-10	0.878392E+08
0.294	172.348100	0.276134E-10	0.881390E+08
0.295	173.605800	0.278149E-10	0.884388E+08
0.296	174.869100	0.280173E-10	0.887386E+08
0.297	176.137800	0.282206E-10	0.890384E+08
0.298	177.412100	0.284248E-10	0.893382E+08
0.299	178.691900	0.286298E-10	0.896379E+08
0.300	179.977300	0.288358E-10	0.899377E+08

Figure of proton kinetic energy vs. its Beta

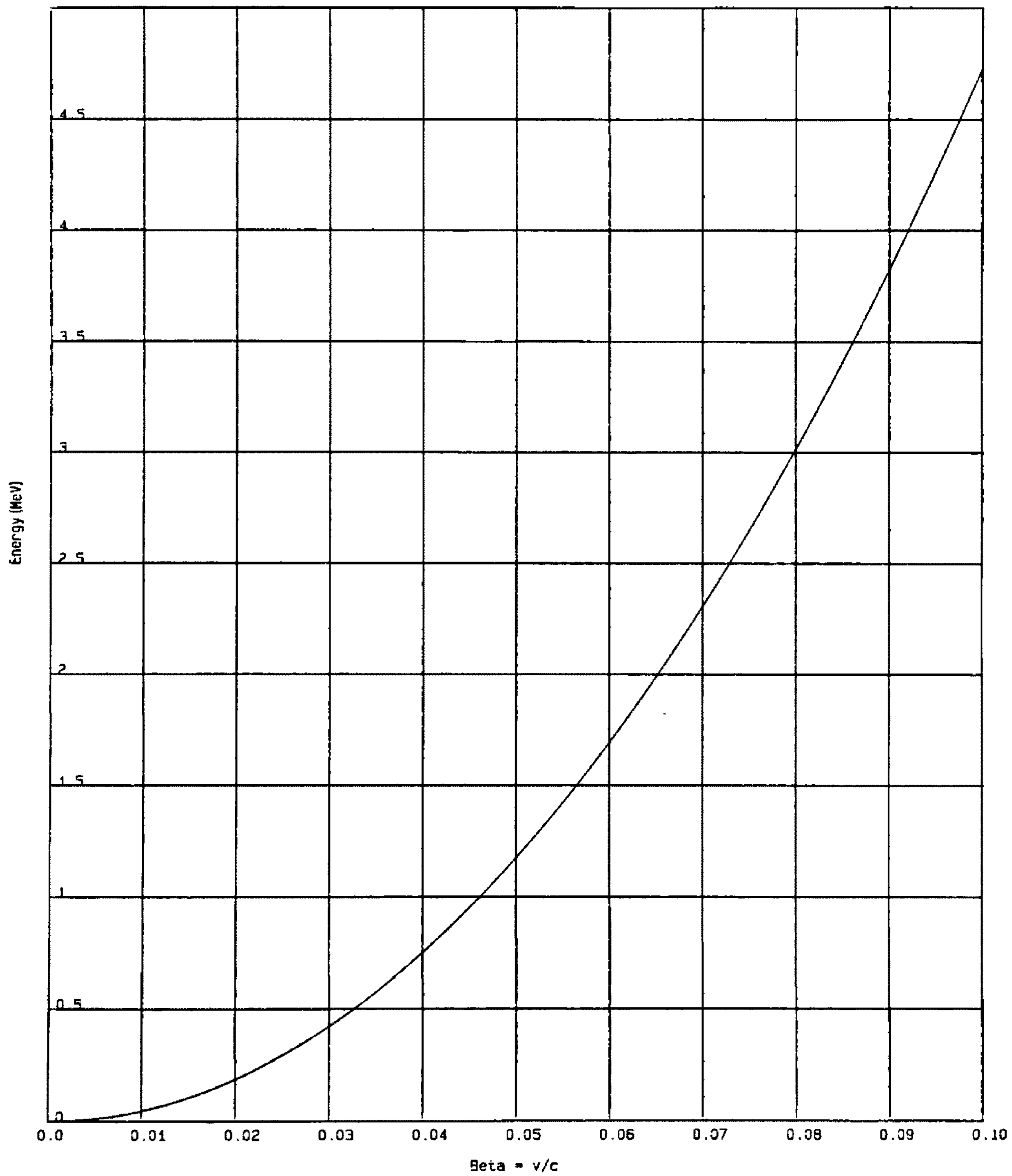


Figure of proton kinetic energy vs. its Beta

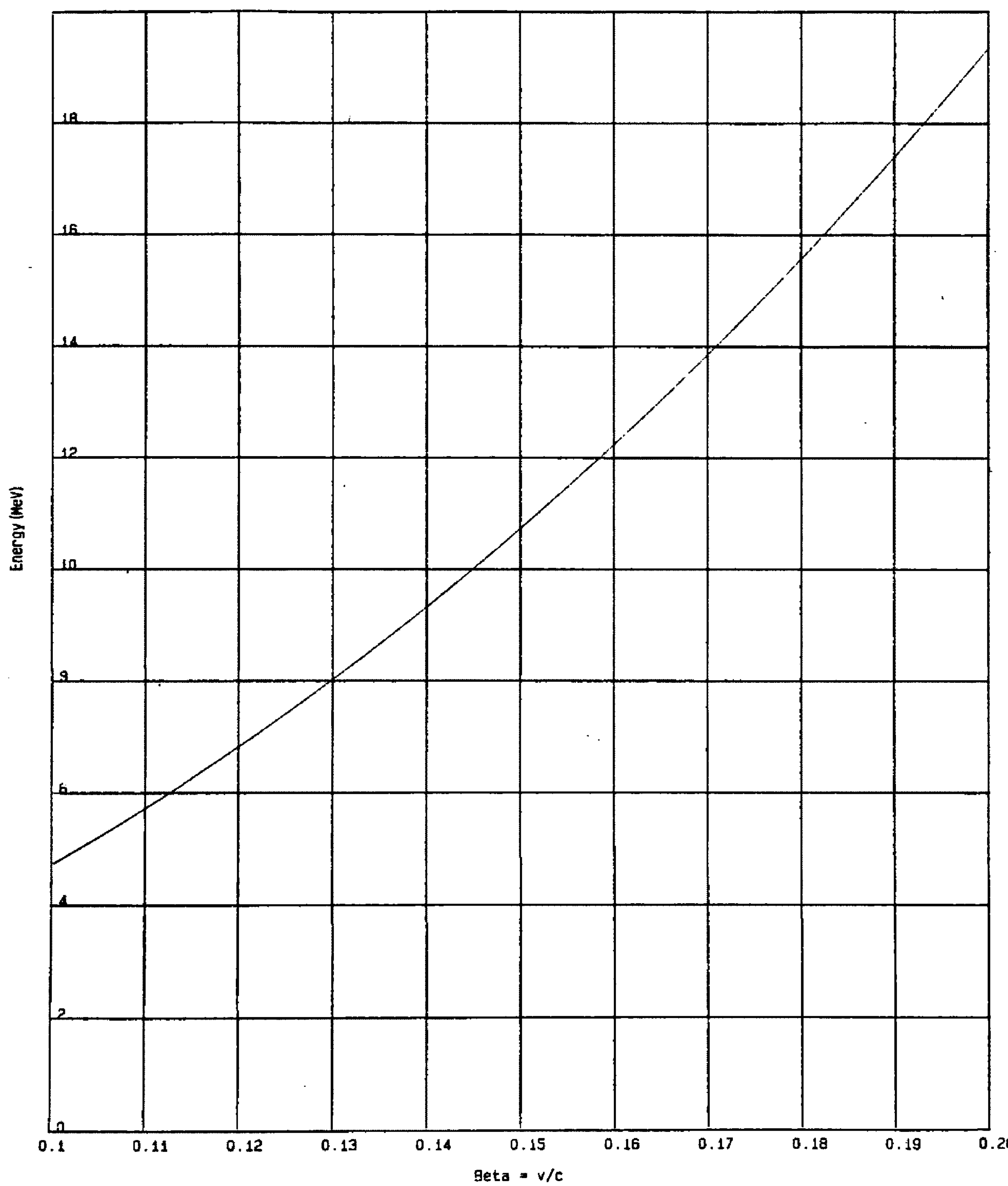


Figure of proton kinetic energy vs. its Beta

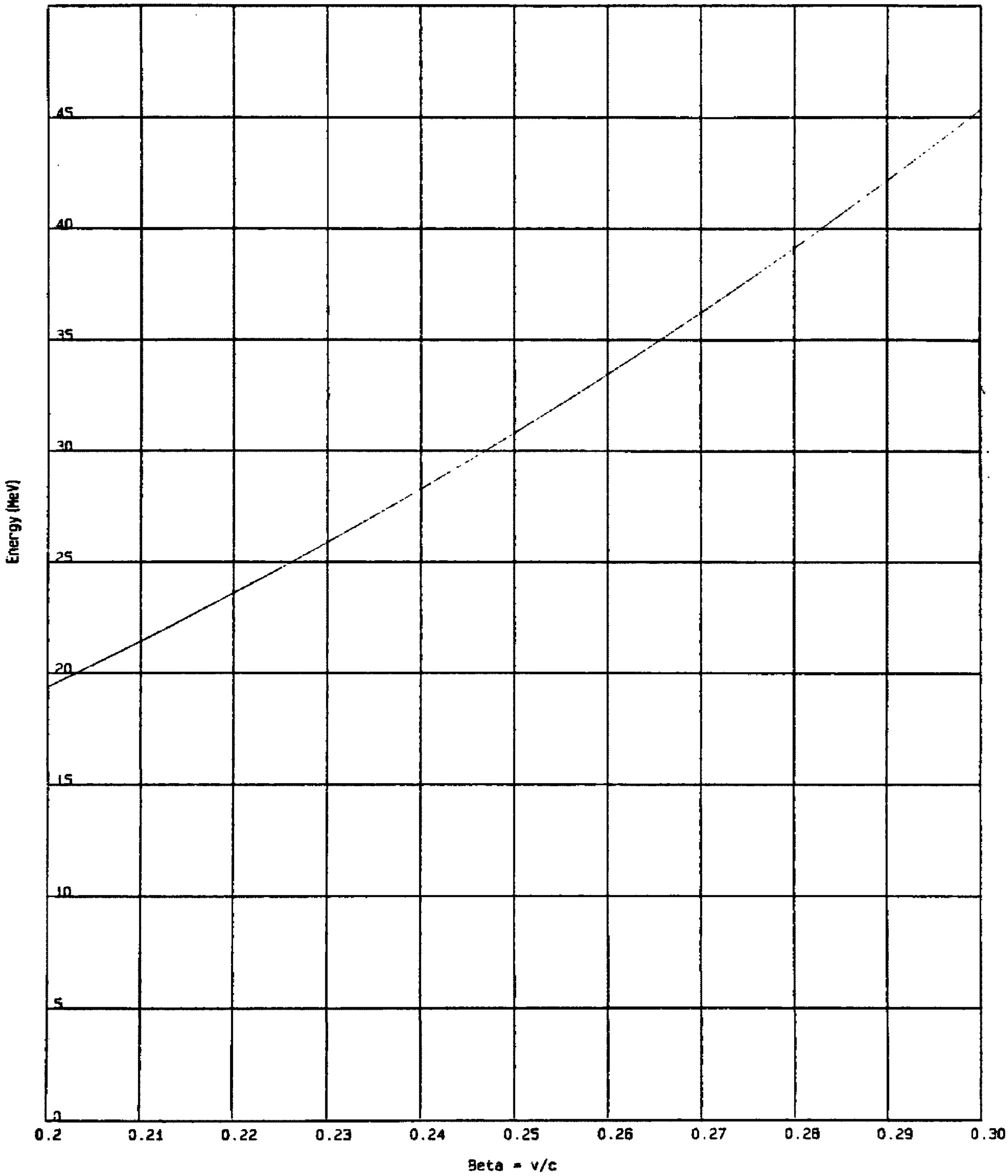


Figure of alpha particle kinetic energy vs. its Beta

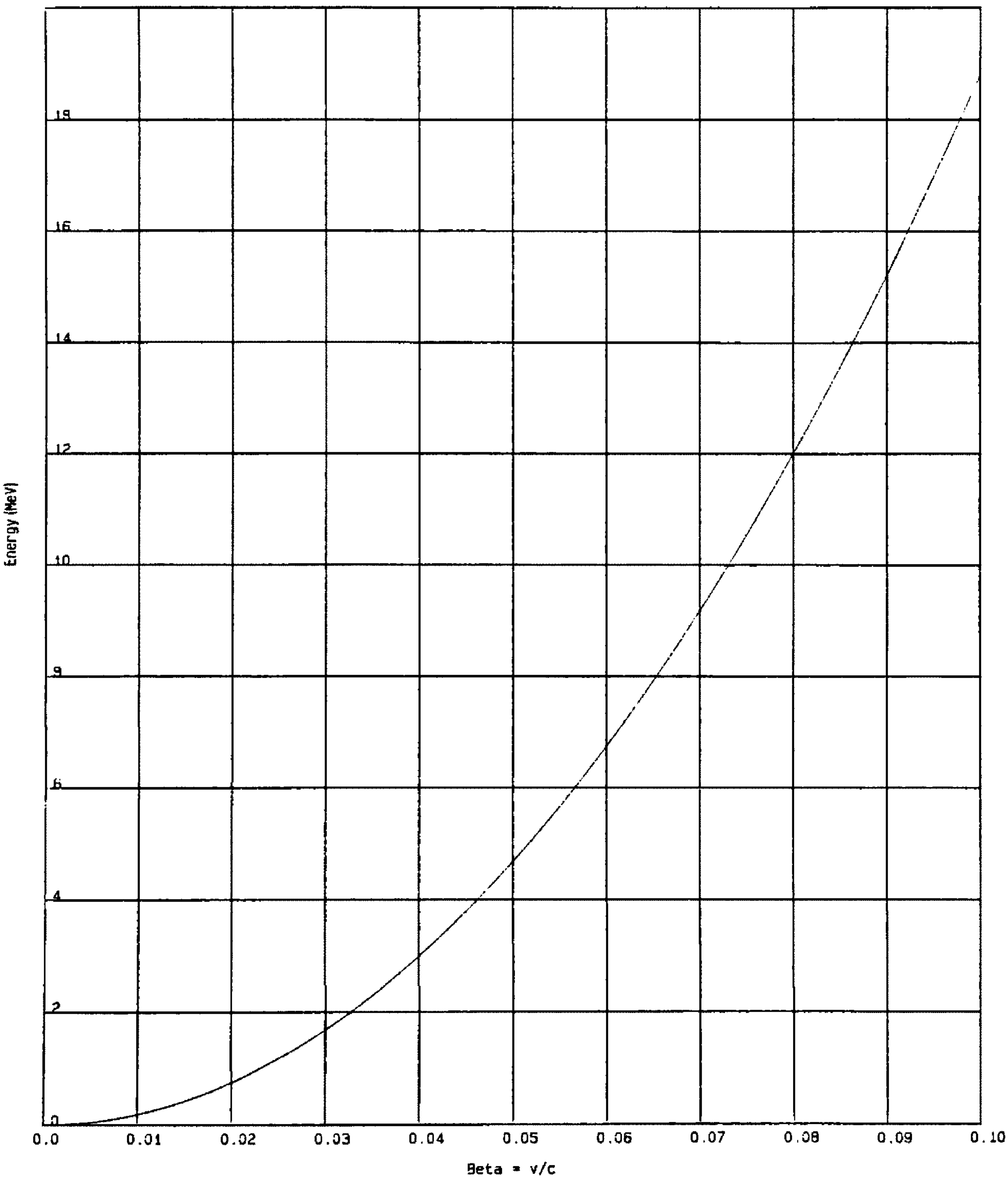


Figure of alpha particle kinetic energy vs. its Beta

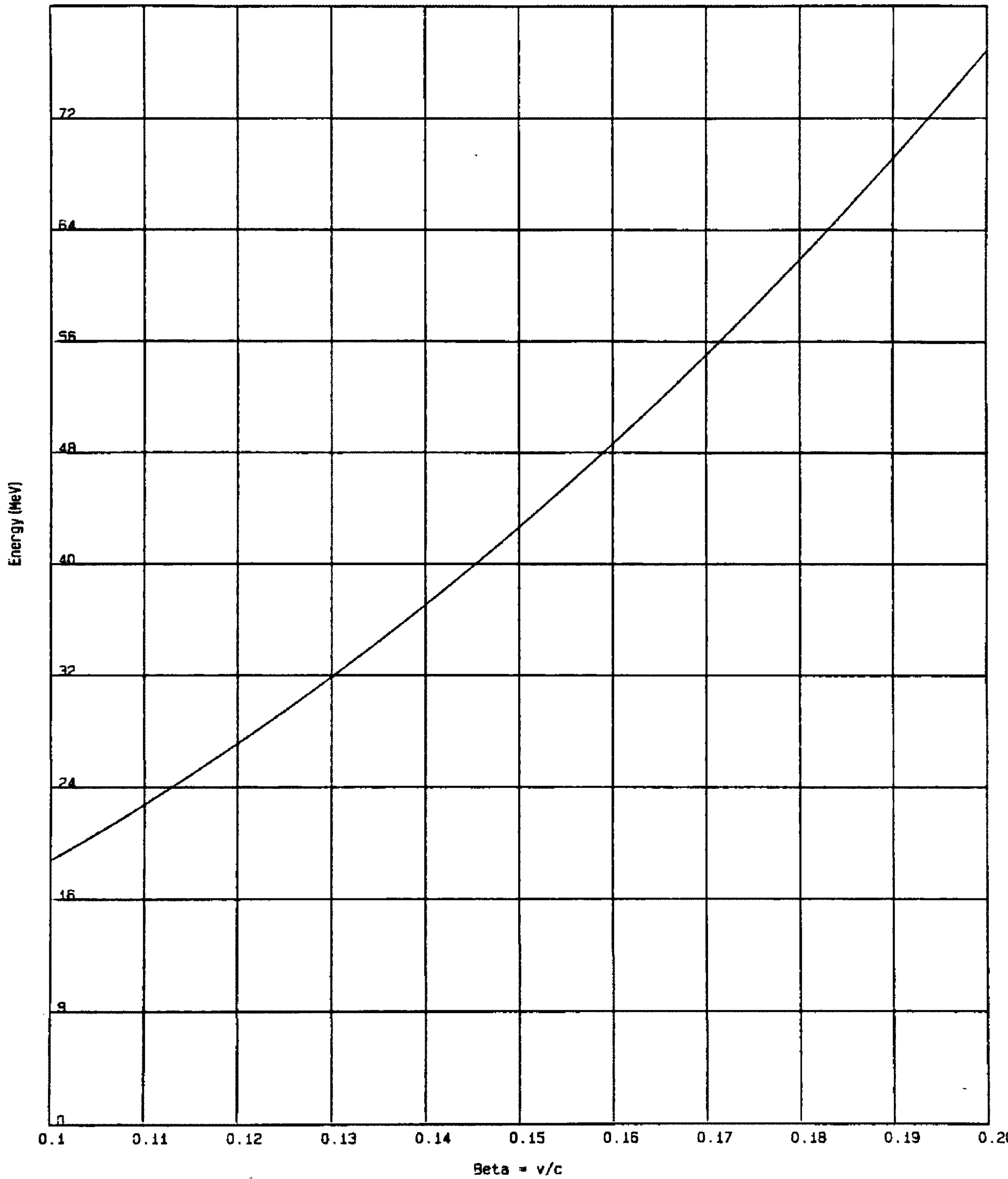
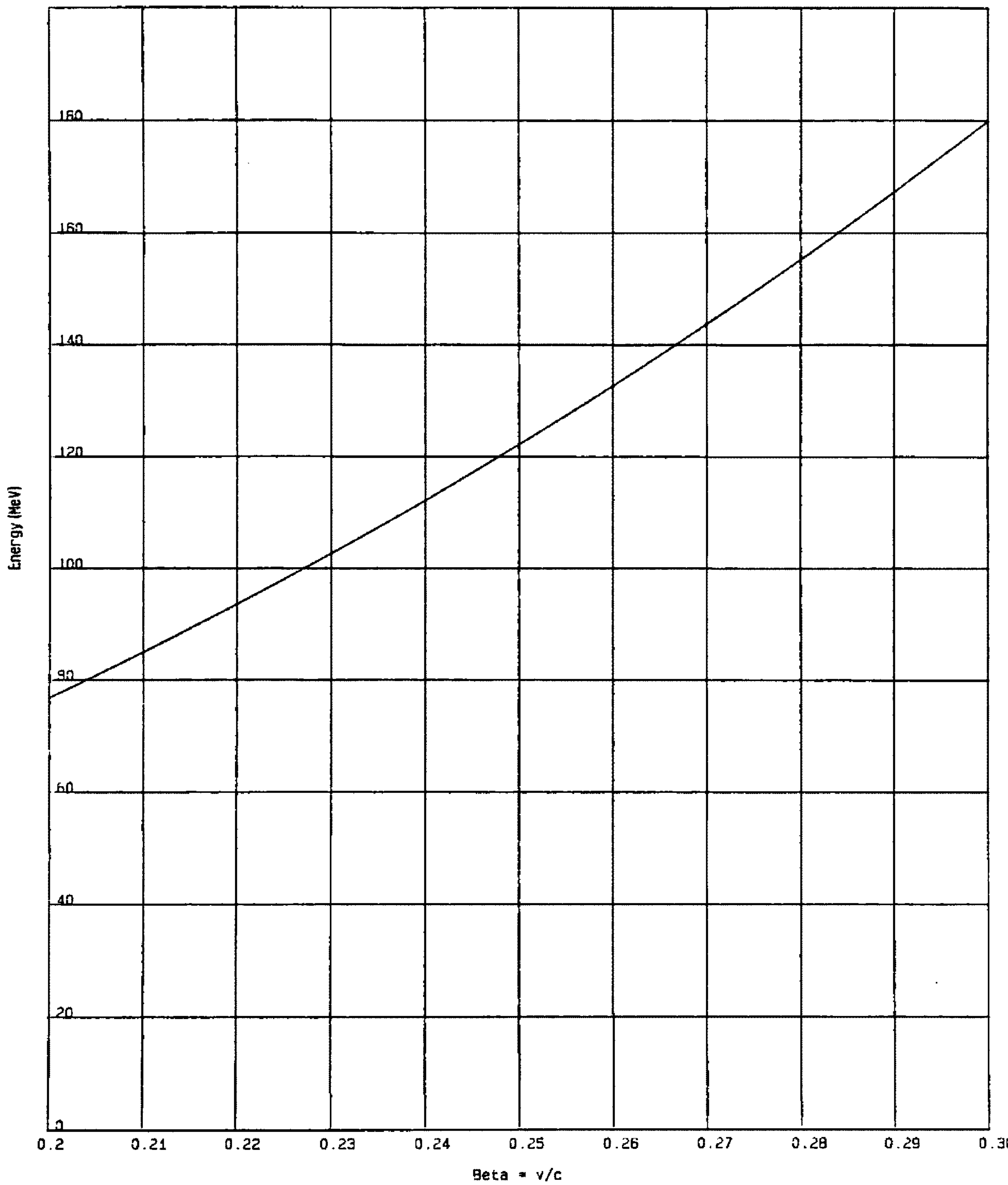


Figure of alpha particle kinetic energy vs. its Beta



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